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ABSTRACT

Energy is a vital topic. Energy costs have risen dramatically during the last decade and home owners are concerned about their energy bills and the costs associated with heating or cooling their homes. An understanding of energy, its sources and ways to reduce its use or improve the efficiency with which people use it will become more important as some of the world's fossil fuel resources approach depletion in the years to come. The purpose of this book is to provide ideas for science projects related to energy. It is designed to help students learn the scientific method as well as proceed with research and set up projects. Chapters include: (1) "Science Projects and Fairs"; (2) "Energy, Work, Power and Efficiency"; (3) "Heat and Thermal Energy"; (4) "Electrical Energy"; (5) "Energy of Motion and Position"; (6) "Solar Energy"; and (7) "Saving Energy at Home and School." A list of selected readings is included. Appendices provide "R Values of Various Materials" and "Specific Heats of Some Common Substances." (CW)

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ROBERT GARDNER

ENERGY PROJECTS FOR YOUNG SCIENTISTS

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ENERGY
PROJECTS FOR YOUNG SCIENTISTS

1

SCIENCE PROJECTS AND FAIRS

Energy is a vital topic today. Energy costs rose dramatically during the last decade, and most homeowners are concerned about their energy bills and the cost of heating or cooling their homes. An understanding of energy, its sources, and ways to reduce its use or improve the efficiency with which we use it will become increasingly important as some of our fossil-fuel energy resources approach depletion in the years to come. Unfortunately, because of OPEC and other controlling factors, the economics of energy have little to do with the availability of oil or other energy sources.

While doing the energy projects suggested in this book, you may discover new questions that you can answer through experiments of your own design. By all means carry out these experiments after consulting with an adult to be sure that they are safe. You are developing the kind of curiosity that characterizes a good scientist.

The purpose of this book is to provide some ideas that will help you get started on a project related to energy. Some of the projects suggested here simply raise questions that will make you think. You will have to design an experimental procedure that answers the question and

SAFETY FIRST

1. **Do all experiments and projects in this book under supervision of a science teacher or other knowledgeable adult—unless such a person has approved your working by yourself.**
2. **Read instructions carefully before proceeding with a project.** If you have questions, check with your "supervisor" before going further.
3. **Maintain a serious attitude while conducting experiments.** Fooling around can be dangerous to you and to others.
4. **WEAR PROTECTIVE GOGGLES AT ALL TIMES. Wear a lab apron when working with chemicals.**
5. **Do not touch chemicals with your bare hands unless instructed to do so. Wash your hands after conducting experiments involving chemicals.**
6. **Do not taste dry chemicals or solutions.** Do not eat food while conducting experiments.
7. **Do not inhale fumes released during a chemical reaction. Do experiments involving any poisonous or irritating gases in a fume hood.**
8. **Keep flammable materials away from heat sources.**
9. **Keep your work area clean and organized. Turn off gas and electricity when they are not being used.**
10. **Have safety equipment such as fire extinguishers, fire blankets, safety showers, and first-aid equipment available while you are experimenting.** Know where this equipment is.
11. **Clean up chemical spills immediately. If you spill anything on your skin or clothing, rinse it off immediately with plenty of water, then report what happened to a responsible adult.**
12. **Be careful about touching glass that has recently been heated; it looks the same as cool glass.** Bathe skin burns in cool water or apply ice.
13. **Avoid touching materials connected to high voltage. Do not touch any source of high voltage.**
14. **Never experiment with household electricity unless supervised by a knowledgeable adult.**

respond to any other questions that arise as your inquiry proceeds.

Other projects contain detailed instructions about how to proceed, but even these usually require some thinking on your part. If you have not had a chance to do much science on your own, you should probably begin with a project that provides reasonably detailed instructions. Once you've had more experience with science and experimentation, you may want to try some of the more open-ended projects, or you may discover questions of your own that you will want to explore. Projects of a more advanced nature are preceded by an asterisk (*).

Many people think of scientists as a group of men and women who possess miraculous memories and an abundance of factual information. The truth is that scientists, like people in all professions, are often forgetful and have to check books and notes frequently for the facts related to their research. What good scientists have in common is an ability to ask the right questions and a way to try to find the answers.

The science presented in textbooks is usually framed in terms of currently accepted theories about the way nature behaves. A reader learns very little about the scientific method from most textbooks. The variations and complexities of scientific investigation make it impossible to describe *the* scientific method. The only way to understand scientific inquiry is to do it. That is why doing science projects, when you don't know the outcome of your experiment or what the right answer is, can help you gain a better understanding of the nature of scientific inquiry.

Percy Bridgman, an American physicist, once said that the scientific method is doing one's utmost with one's mind, no holds barred. A more scholarly definition was given by James B. Conant: "Science emerges from other . . . activities of man to the extent that new concepts arise from experiments and observations." These new concepts or theories, he went on to say, stimulate

the development of new experiments that confirm, modify, or cause us to discard the concept.

Conant's definition makes it clear that scientific inquiry is a dynamic human process in which theories and ideas change as new information accumulates.

The word *observation* in Conant's definition refers to the gathering of factual data, not just watching experiments as they take place. Gathering information requires the careful use of the investigator's sense organs, for our senses can be fooled easily. The observations we make may be planned, as when we set out to investigate a question that interests us, or they may be accidental. In more cases than the writers of textbooks would have us believe, crucial observations were made by accident.

Boyle's discovery of the law that bears his name arose from observations he made while attempting to disprove a theory proposed by another scientist. Darwin came to the idea of natural selection while reading a book by Malthus. Oersted discovered the first connection between electricity and magnetism while preparing a demonstration designed to show that there was no connection between these two phenomena.

In an attempt to explain a set of observations, scientists often develop a working hypothesis. Developing such a hypothesis requires a "leap of the imagination" in attempting to present an explanation of the observations and the relationships among them. From this hypothesis, which is a generalization designed to explain factual information obtained by one or more investigators, scientists deduce specific consequences that follow from the hypothesis. They, or someone else, then design experiments that they hope will confirm or deny the hypothesis. Even if experimental results confirm the prediction deduced from the hypothesis, the hypothesis is not proven. It merely gives additional evidence that it may be true.

Hypotheses and theories are never proven in science; they only gain increasing certitude as more and more supporting evidence is acquired. If an experiment shows the hypothesis to be wrong, it may be modified or dis-

carded. However, scientists, like most humans, often cling to hypotheses they regard as elegant even though the evidence disputes their validity.

When a broad working hypothesis, one that explains a large number of observations, has been confirmed by a great variety of experimentation, the term *theory* is often applied. For example, much of Dalton's hypothesis about the atomic nature of matter is now referred to as the atomic theory because it has been confirmed by repeated experimentation. Of course, this experimentation has gone on for nearly 200 years and the theory has been modified and is still being modified to this day. This is what we mean when we say science is a dynamic process. No explanation of nature's behavior is written in stone. There is always the possibility that today's explanation will be modified or replaced tomorrow.

What scientists come to after experimental checks and counterchecks, arguments, discussions, and tests of alternative explanations is a model or theory that explains some aspect of our universe. And what every scientist realizes is that that model may change as new information is gathered.

Underlying all scientific inquiry is the faith that nature is uniform, that experimental results obtained in New York today can be confirmed by similar experiments conducted in London next year. Only through such a faith can science arrive at relationships and explanations that have meaning to all. Experimental results must be repeatable. If your data does not agree with that of someone else who does the same experiment, scientists will not accept the conclusions you make because they are based on data that cannot be confirmed.

In many cases, where a variety of causes are suspected, a scientist will try first one thing and then another in a trial and error fashion looking for the one that gives the desired effect. This was the method used by Thomas Edison in much of his research. Unlike many scientists, Edison was not an analytical person who thought deeply about problems. He succeeded by great effort and determination, which probably explains his statement,

"Genius is one percent inspiration and ninety-nine percent perspiration."

The purpose of this book is to provide as many ideas for energy projects as possible within the confines of these pages. If you are interested in using some of these projects as material for a science fair, you should consult a book devoted to the preparations you must make before entering such a fair. A few such books are:

How Fast Do Your Oysters Grow, by Norman F. Smith (New York: Messner, 1982).

How to Do a Science Fair Project, by Salvatore Tocci (New York: Watts, 1986).

How to Do a Science Project, by David Webster (New York: Watts, 1974).

PROJECTS AND PEOPLE ON DISPLAY AT A SEER SCIENCE FAIR SPONSORED BY THE NATIONAL ENERGY FOUNDATION.

AN EXHIBITOR AND HER EXHIBIT AT A SEER FAIR.

Ideas for Science Projects, by Ronald Benrey et al. (New York: Arco, 1961).

Nuts & Bolts: A Matter of Fact Guide to Science Projects, by Barry A. Van Deman and Ed MacDonald (Harwood Heights, Ill.: The Science Man Press, 1980).

So You Want to Do a Science Project, by Joel Beller (New York: Arco, 1982).

Winning with Science, by William S. Loiry (Sarasota, Fl.: Loiry Publishing, 1983).

Your teacher or an adult who may have helped you with your project may be able to provide information about state and local science fairs if you are interested in entering one. Listed below are some of the national com-

ANOTHER EXHIBITOR AT A SEER FAIR.

petitions related to science fairs or research. If you are interested, write to the address provided for more information.

Earthwatch offers research internships in various science projects throughout the world. Write to:
Earthwatch, 10 Juniper Road, Box 127, Belmont, MA 02178

International Science and Engineering Fair is sponsored by General Motors and nearly fifty other organizations. Projects may be in any of twelve categories ranging from computers to zoology. Write to:
Science Service, 1719 N Street NW, Washington, D.C. 20036

JETS holds a contest for projects in engineering. Write to: Junior Engineering Technical Society, 345 E. 47th Street, New York, NY 10017

National Energy Foundation runs energy education programs and science fairs (among them SEER—Student Exposition on Energy Resources). Write to:
National Energy Foundation, 5160 Wiley Post Way, Suite 200, Salt Lake City, UT 84116

National Science Foundation Science Training Project is a program sponsored by NSF that offers science training at a variety of schools, colleges, and laboratories during the summer months. Write to:
Public Information Branch, National Science Foundation, Washington, D.C. 20550

NSTA/NASA Space Shuttle Student Involvement Project provides students with an opportunity to propose experiments to be done aboard the Space Shuttle. Write to:
National Science Teachers Association, NSTA/NASA Space Shuttle Student Involvement Project, 1742 Connecticut Avenue, NW, Washington, D.C. 20009

Westinghouse Science Talent Search provides scholarship awards to winners of this program, which involves independent research in the physical, biological, behavioral, and social sciences, as well as mathematics and engineering. Write to:
Science Service, 1719 N Street NW, Washington, D.C. 20036

UNITS

You will find abbreviations for units used in this book. A list of these abbreviations and the units they represent can be found in Table 1 on the next page.

TABLE 1
Units and
Their Abbreviations

Length
foot (ft)
inch (in)
mile (mi)
millimeter (mm)
centimeter (cm)
meter (m)
kilometer (km)

Area
square foot (sq ft)
square inch (sq in)
square centimeter (cm^2)
square meter (m^2)

Volume
cubic foot (cu ft)
cubic inch (cu in)
ounce (oz)
milliliter (ml)
cubic centimeter (cm^3)
cubic meter (m^3)
liter (liter)

Force/weight/mass
newton (N)
pound (lb)
kilogram (kg)
gram (g)
milligram (mg)

Power
watt (W)
kilowatt (kW)
horsepower (hp)

Energy
joule (J)
newton-meter (N-m)
British thermal unit (Btu)
calorie (cal)
Calorie (Cal)
kilowatt-hour (kWh)
foot-pound (ft-lb)

Electrical units and their equivalents
volt (V) = joule/coulomb (J/C)
ampere (A) = coulomb/second (C/s)
coulomb (C) = ampere-second (A-s)
ohm (Ω) = volt/ampere (V/A)

Temperature
degree Celsius (°C)
degree Fahrenheit (°F)

Temperature-time
degree-day (DD)

Time
hour (h)
minute (min)
second (s)

Others
change in (Δ)
angle (ϕ)
kinetic energy (K.E.)
gravitational potential energy (GPE)

2

ENERGY, WORK, POWER, AND EFFICIENCY

Many people use the words *energy*, *work*, and *power* as if they all meant the same thing. Some science textbooks even define energy as the ability to do work, but such a definition is oversimplifying the facts.

ENERGY AND WORK

Work (W) is defined as the product of the net force (F) exerted on a body (in a direction parallel to the body's motion) and the distance (d) through which that force acts. In mathematical terms:

$$\text{Work} = (\text{Force})(\text{distance})$$

$$\text{or } W = Fd$$

$$\text{or better, } W = F\cos\phi d,$$

where ϕ is the angle between the direction of the force and the direction the body moves.

If you lift a weight, W, through a height, h, the work you do is Wh. If you lift the weight twice as high, you do twice as much work. But if the weight is too heavy for you to lift, you do no work in attempting to lift it. Even though you exert large forces, the distance through which the

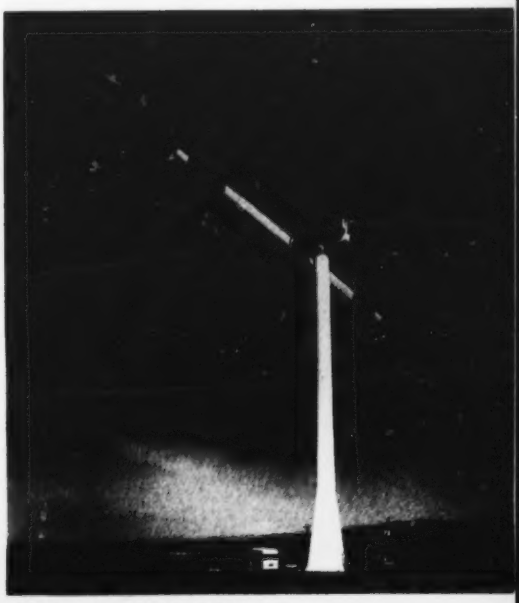
force acts is zero; consequently, the product of force and distance is zero.

Energy is a more subtle notion. You can't see, feel, touch, or taste energy. In fact, we can't really define energy. It is an intangible; yet, it appears in many familiar but different forms that can be defined. Kinetic energy, the energy of motion, is defined as $\frac{1}{2}mv^2$, where m is the mass of the moving body and v its velocity. Gravitational potential energy is defined as the product of a body's weight and its height above some level surface. Similarly, thermal energy (heat), electrical energy, light, elastic potential energy, as well as nuclear and chemical energy can all be defined.

The quality common to all forms of energy is the fact that one form can be transformed into another. For example, the gravitational potential energy stored in a ball lifted above the ground can be changed into kinetic energy as it falls. The kinetic energy is then transformed into elastic potential energy (the energy stored in any springlike device) as the ball is compressed upon striking the ground. The elastic energy is converted back into kinetic and then potential energy as the ball bounces upward. However, succeeding bounce heights become progressively less until finally the ball is at rest.

Careful measurements will show that the thermal energy (the total kinetic energy of the molecules of a sample of matter) added to the ball and its surroundings is equal to the original energy stored in the ball as gravitational potential energy. The various forms of energy associated with the falling and bouncing ball have been transformed into thermal energy.

Similarly, chemical energy (the energy stored in molecules) can be converted into the thermal energy needed to heat your home. Or the same energy can be used to produce steam that can turn an electrical turbine or drive a piston in the cylinder of a steam engine. The moving piston or electrical energy can then be used to do work. In either case, the amount of work done is always less than the loss in chemical energy. In every energy transfer some thermal energy "rubs off" because



ABOVE LEFT: IN A MISSILE, ENERGY PRODUCED BY THE BURNING OF FUEL IS CONVERTED INTO THRUST. ABOVE RIGHT: A WINDMILL CONVERTS SOLAR ENERGY IN THE FORM OF WIND INTO ROTATIONAL ENERGY, WHICH IN TURN PRODUCES ELECTRICAL ENERGY. LEFT: SOLAR ENERGY ALSO PROPELS A BICYCLE. HOW'S THAT? PLANTS UTILIZE SUNLIGHT TO CREATE THEIR OWN ENERGY. ANIMALS—INCLUDING HUMANS—DERIVE SOME OR ALL OF *THEIR* ENERGY FROM PLANTS. HUMANS THEN USE SOME OF THIS ENERGY WHEN THEY PEDAL A BICYCLE!

of friction in bearings, air, or the movement of one surface over another. The energy transformed from one form to another can be measured by the amount of work done.

For example, suppose a ball that weighs 1 lb falls through a height of 1 ft and bounces to a height of ½ ft. We know that half the gravitational potential energy has been lost because the work required to lift a ball 6 in is only half that required to lift the ball 1 ft.

POWER

Power is the rate of doing work. A powerful engine is one that can do a lot of work in a short period of time. In mathematical terms:

$$\text{Power} = \text{work/time, or } P = W/t$$

James Watt was the first person to measure power in units called horsepower. He measured the rate at which horses could raise heavy weights from a deep well and found that they averaged about 550 foot-pounds (ft-lb) of work per second.* This value is still used today. When we say an engine has 100 horsepower (hp), it means that the machine can do 55,000 foot-pounds of work per second.

Another unit of power is the watt (W), which is commonly used to measure electrical power. One watt is 1 joule per second;† a kilowatt (kW) is 1,000 W or 1,000 joules per second (1000 J/s).

PROJECT 1:
How powerful are you?

Do you think you can work like a horse? You may be surprised to find that you or one of your friends actually can work that hard.

*A foot-pound is the work done by a force of 1 lb acting through a distance of 1 ft.

†A joule (or newton-meter) is the work done by a force of 1 N acting through a distance of 1 m.

RACING CARS ARE POWERFUL! THEY, TOO, ARE SOLAR POWERED,
SINCE THE OIL THEY BURN COMES FROM DECOMPOSED PLANTS.

When you walk up a flight of stairs, you do some work on yourself. If you run up the stairs, you do the same work in a shorter time and therefore develop more power.

To determine how much power you can develop, have someone measure the time it takes you to run up a long flight of stairs. To calculate your power you will need to know the *vertical* height of the stairs, your weight, and the time it took you to ascend the stairs. The product of your weight and the height of the stairs is the work you did on yourself. Dividing that work by the time required to do it will give you your power. For example, if you weigh 120 lb and run up a flight of stairs 12 ft high in 4.0 s, your power can be calculated as shown below.

$$\text{Power} = \frac{\text{weight} \times \text{height of stairs}}{\text{time}} = \frac{120 \text{ lb} \times 12 \text{ ft}}{4.0 \text{ s}}$$

$$= 360 \text{ ft-lb/s} = 0.66 \text{ hp}$$

Try it! Are you as powerful as a horse?

PROJECT 2:
Power and people

Use the same method to find how much horsepower other people can develop. What do you find? Is the power that a person can develop related to age? Sex? Height? Weight? If you measure the power that people can develop over a greater height, say five flights of stairs instead of one or two, it will affect an individual's power. Can you explain why?

EFFICIENCY

As you read earlier, some thermal energy always "rubs off" when energy is transformed from one form to another. Consequently, the amount of energy transferred into a machine is always greater than the energy that the machine transfers out. The efficiency of any device is the ratio of the energy input to the energy output. Since we always get less energy out of a device than we put into it, its efficiency is always less than 1.0.

PROJECT 3:
How efficient is your bicycle?

Many bicycles are built so that the rider can change gears. This makes it easier to pedal up hills. But when you make a bike easier to pedal, you sacrifice speed. You have to exert less force, but the bike's wheel doesn't go as far per turn of the sprocket gear attached to the pedals.

To measure the efficiency of a bicycle under the best conditions possible, that is, when the wheels are off the road and free to turn, you will need a multi-speed bike, string and tape, and a pair of sensitive spring scales. Turn the bike upside down. Use string and tape to attach one spring scale to a pedal and the other to the back tire. Figure 1 shows you how to do this.

Start with the bike in low gear—the one used to pedal up steep hills. Pull on the pedal with a fairly strong force. This is the input force. At the same time have a

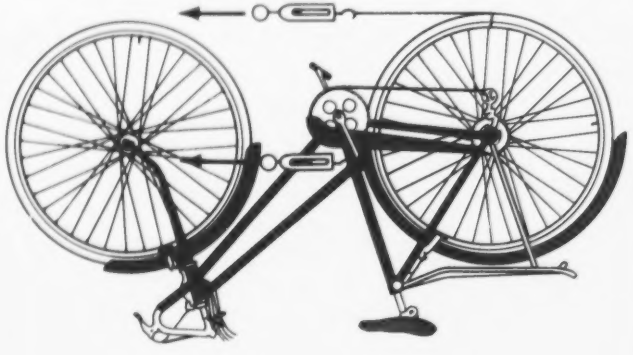
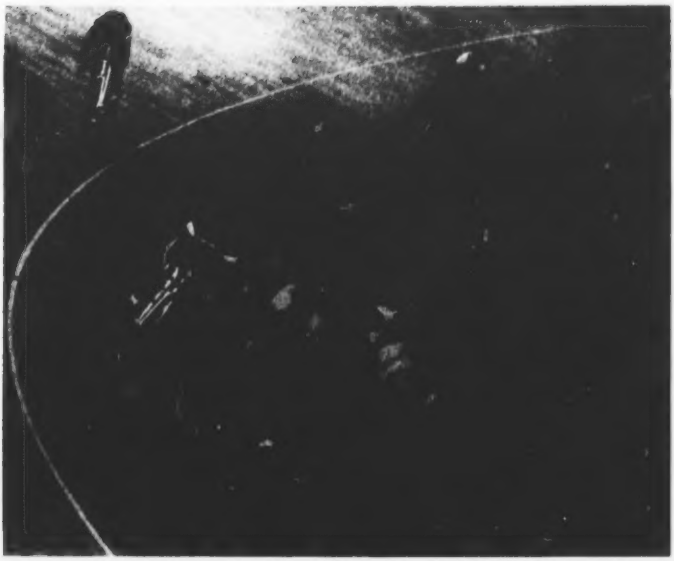


Figure 1 An upside-down bike and spring scales



RACING CYCLISTS BEND WAY OVER TO MINIMIZE WIND RESISTANCE.

partner measure the force needed to keep the wheel from turning. This tells you the output force, the force that is exerted on the wheel and also the force that the wheel could exert on the road. Next measure the distance that the pedal moves when it goes around once. Then slowly and carefully measure the distance a point on the tire moves when the pedal makes one turn.

You now have enough information to calculate the work put into the bike, the work that can come out of the bike, and, hence, the efficiency of the bike under ideal conditions. How efficient is the bicycle? What do you find about the input and output forces, and the bike's efficiency when you use different gears?

How could you measure the efficiency of the same bicycle under road conditions? One approach might be

to let your full weight fall through the change in height that occurs when a pedal turns halfway around, from its highest to its lowest position. The distance that you fall while pushing on the pedal times your weight will measure the energy put into the bike. The kinetic energy of the bike and rider after the pedal reaches its lowest position can be used to measure the energy output.

Find some other ways to measure the input and output energies for the bicycle.

How efficient is the bicycle under road conditions? What is the effect of different gear ratios on its efficiency? Does the weight of the rider have an effect on the bike's efficiency? How about the air pressure in the tires?

3

HEAT AND THERMAL ENERGY

Matter is made up of atoms and molecules. These particles are in constant motion as they jostle one another about. The total kinetic energy of the molecules within a sample of matter is what we call thermal energy. The *average* kinetic energy of the molecules of a substance is proportional to the temperature of that substance. When the average kinetic energy doubles, the temperature doubles.

Heat is the thermal energy transferred from one body to another because of a difference in temperature. Heat "flows" from a warmer body to a cooler one. When the molecules of the warmer substance collide with those of the cooler substance, some kinetic energy is transferred through the collisions to the slower-moving molecules. If left in contact for some time, both samples of matter will come to the same temperature and, therefore, the same average kinetic energy.

The concept of heat is introduced early in this book because all other forms of energy can be converted to thermal energy. For example, the gravitational potential energy of a body can be transformed into thermal energy by attaching the body to a piece of plastic twine wrapped around a fixed metal cylinder. As the body falls,

the plastic twine rubs against the metal and transfers heat to the metal, causing its temperature to rise.

MEASURING HEAT

To know how much heat is transferred from one body to another, we have to find a way to measure heat. The following projects will help you understand what factors are involved in making such measurements.

To perform these projects you will need an immersion heater, the kind used to heat water for a single cup of tea. If you or your school do not own an immersion heater, you can buy one in a supermarket or department store. Be sure the heater is well insulated so that there is no danger of electric shock. When you disconnect such a heater, always pull the plug from the electric outlet; do not pull on the cord that connects the plug to the heater. **Never insert the plug into an electrical outlet unless the heater is in water or another liquid.**

PROJECT 4:
Heat and temperature change

To find out how the change in temperature of a substance is related to the amount of heat transferred to it, you can supply different amounts of heat to a fixed mass of water. If you were to change the mass of the water, you would not be able to tell whether the change in temperature was the effect of the heat or the mass. By keeping the mass fixed, you can be sure that you are testing the effect of heat on temperature change.

It seems reasonable to assume that the heat delivered by an immersion heater when it is plugged in for 30 s will always be the same or "within the experimental error." By the same reasoning you can assume that an immersion heater plugged in for 60 s will deliver twice as much heat as one plugged in for 30 s. You can call the amount of heat that is transferred by an immersion heater in 30 s 1 *glug* of heat. Then the heat delivered by the immersion heater in 1 min will be 2 glugs, and so on.

Place 100 ml of cold water in an insulated coffee cup. Measure the temperature of the water with a thermometer calibrated in degrees Celsius. Heat the water with an immersion heater for 15 s. Stir the water with the heater as it warms the liquid. After 15 s pull the plug but *leave the heater in the cup* so that all the heat produced can be transferred to the water. Stir thoroughly and record the new temperature and the temperature change of the water.

Repeat the experiment several times. Use the same amount of water but increase the heat delivered from 0.5 glug to 1.0 glug, 1.5 glugs, and 2.0 glugs. Be sure to use a new sample of cold water for each run because warm water loses heat to the surroundings faster.

How is the temperature change of the water related to the quantity of heat it receives?

PROJECT 5:
Heat and mass

To see how heat and mass are related, we will vary the mass of the water as we vary the heat in an effort to keep the temperature change constant. If heat is directly proportional to mass, doubling both the heat transferred and the mass of water heated should result in the same temperature change.

Using your immersion heater, add one glug of heat to 100 g (100 ml) of cold water. The density of water is 1.0 g/ml. Repeat the experiment using 200 g (200 ml) of cold water and 2 glugs of heat. In a large insulated cup (12 oz or larger) try 3 glugs and 300 g and 4 glugs and 400 g. Are the temperature changes of the water close to being constant for all these runs? If they are, what does that tell you about the relationship between heat and mass?

PROJECT 6:
Mass and temperature change

From what you have found experimentally about heat and mass and heat and temperature change, what

would you expect to find about the temperature change if you kept the amount of heat transferred constant while increasing the mass of the water heated?

To test your prediction, add 1 glug of heat to 100 g of cold water. What is the temperature change of the water? What is the temperature change when you add 1 glug of heat to 200 g of cold water? To 300 g of cold water? To 150 g of cold water? Is your prediction borne out by these experiments?

What is the relationship between mass of water and temperature change when the heat transferred is constant? What will a graph of mass versus temperature change look like when the heat transferred is kept constant? How about a graph of the inverse of mass (1/mass) versus temperature change?

PROJECT 7:
A formula for heat

Your experiments have probably convinced you that heat is proportional to the temperature change of water and to the mass of the water heated. If something, in this case heat, is proportional to both of two variables, in this case temperature change and mass, then it (heat) is proportional to the product of these variables. For example, the area of a rectangle is proportional to both the length and the width of the rectangle.

To see if heat is proportional to the product of mass and temperature change, make a chart like the one below using the data you have collected in the three projects above. (A sample set of data, not necessarily the same as yours, is shown in the chart.)

Heat (glugs)	*Mass of water (g)*	*Temperature change (°C)*	*Temperature change × mass (g·°C)*
1.0	150	13.0	1,950
1.0	100	20.0	2,000
1.0	200	10.0	2,000

According to your data, is the heat transferred to the water proportional to the product of the water's mass and temperature change?

UNITS OF HEAT

From experiments above, you have seen that the amount of heat transferred to water is proportional to both the temperature change and the mass of the water. You could go on measuring heat in glugs if you wanted to, but few people would know what you were talking about. However, there are units of heat based on the proportionality between heat and the product of mass and temperature change that are commonly used in science and engineering.

One unit for measuring heat is the calorie. A calorie (cal) is defined as the amount of heat required to raise the temperature of 1 g water through 1°C. The large Calorie (Cal), used in nutrition and medicine, is defined as the amount of heat required to change the temperature of 1 kg water 1°C. Another common unit of heat used in engineering and the building industry is the Btu. A Btu is the amount of heat required to change the temperature of 1 lb water by 1°F. The joule (J), a unit of heat used in science, is the amount of heat needed to raise the temperature of 1 g water through 0.24°C.

The units of heat discussed above are all based on the transfer of heat to water, but few substances can "absorb" as much heat per degree of temperature change as water. To take into account the differences in the quantity of heat that equal masses of different substances absorb, scientists introduced a notion called *specific heat*. The specific heat of a substance is the amount of heat needed to raise the temperature of 1 g of the substance through 1°C, or 1 lb of the substance through 1°F. Since it takes 1 cal to change the temperature of 1 g of water 1°C, the specific heat of water is 1 calorie per gram per degree Celsius.

PROJECT 8:
Specific heat

To find the specific heat of a liquid, begin by placing an immersion heater in 100 g of cold water in an insulated coffee cup. Measure the temperature change of the water after the heater is plugged into an electrical outlet for 30 s. (Be sure to stir the water and to leave the heater in the water after the plug is pulled so that the maximum amount of heat will be transferred.)

How much heat, in calories, was transferred to the water? How much heat does the immersion heater "deliver" in 30 s?

Repeat the experiment but this time use 100 g of cold cooking oil. (Be sure the heater does not touch the styrofoam cup. If it does, it may melt the material and give rise to a real mess when the oil leaks from the cup.) What *volume* of cooking oil will you need if you are to have a mass of 100 g? Remember, you have found the number of calories that the heater transfers in 30 s. In the same time an equal amount of heat will be transferred to the cooking oil. What was the temperature change of the cooking oil? What is the specific heat of cooking oil?

After rinsing the immersion heater thoroughly, determine the specific heat of antifreeze (ethylene glycol) using the same technique. What is the specific heat of antifreeze according to your data?

To determine the specific heat of a piece of metal such as aluminum, brass, iron, or lead, place the metal in boiling water (**be careful**). Once the metal is at the temperature of the boiling water, quickly (so as to lose as little heat as possible to the air) transfer the metal to some cold water in an insulated cup. The heat transferred to the water obviously came from the hot metal. Knowing the metal's mass and temperature change, calculate its specific heat.

For example, suppose a 20-g piece of aluminum at 100°C is added to 50 g of water at 20.0°C. If the water temperature rises to 29.9°C, then the metal transferred

445 cal of heat to the water. The heat transferred by the metal per gram per degree would be:

$$445 \text{ cal}/20 \text{ g}/9.9°\text{C} = 02.2 \text{ cal/g/°C}$$

The specific heat of the aluminum is 02.2 cal/g/°C.

Find some different metals and see if you can determine the specific heat of each one. You will have to adjust the mass of water and metal used to obtain reasonable and significant temperature changes.

PROJECT 9:
Identifying metals

Collect some samples of different solid-metal elements. By measuring the density and specific heat of each one, see if you can identify each metal.

PROJECT 10:
Flame temperatures

You can't measure the temperature of a flame by putting a thermometer into the flame; it will only break the thermometer. But suppose you had a small piece of metal, such as an iron or copper washer, whose mass and specific heat you knew. You could hang the metal on a wire held by a clothespin, insert it into the flame, and heat the metal to the temperature of the flame. Then you could quickly drop it into some cold water.

How would this enable you to determine the flame's temperature? How would you know how long it took the metal to reach the temperature of the flame?

Measure the temperature of a variety of flames—bunsen burner, candle, alcohol burner, and match. Are they all the same? **Be careful when using these sources of heat.**

SOURCES OF
ENERGY FOR HOMES

All forms of energy can be transformed into thermal energy. In some of the chapters that follow, you will see that it

is possible to change kinetic, potential, light, elastic, electric, and nuclear energy into thermal energy.

One source of energy that is becoming increasingly common as a means of heating water and homes is solar energy. The roofs of many homes support solar panels that face the sun and convert solar radiation into thermal energy that is used to heat water and/or air.

There are several sources of the kinetic energy in the giant turbines that turn electric generators in power plants and thereby produce electric energy. One source is the kinetic energy in water that has fallen from the tops of dams. A second is the steam produced by burning fossil fuels (coal, oil, or natural gas). In many of the power plants built in the last three decades, the thermal energy used to generate steam comes from the energy released when radioactive elements such as uranium and plutonium undergo nuclear fission. This process involves a loss in mass that gives rise to tremendous amounts of energy.

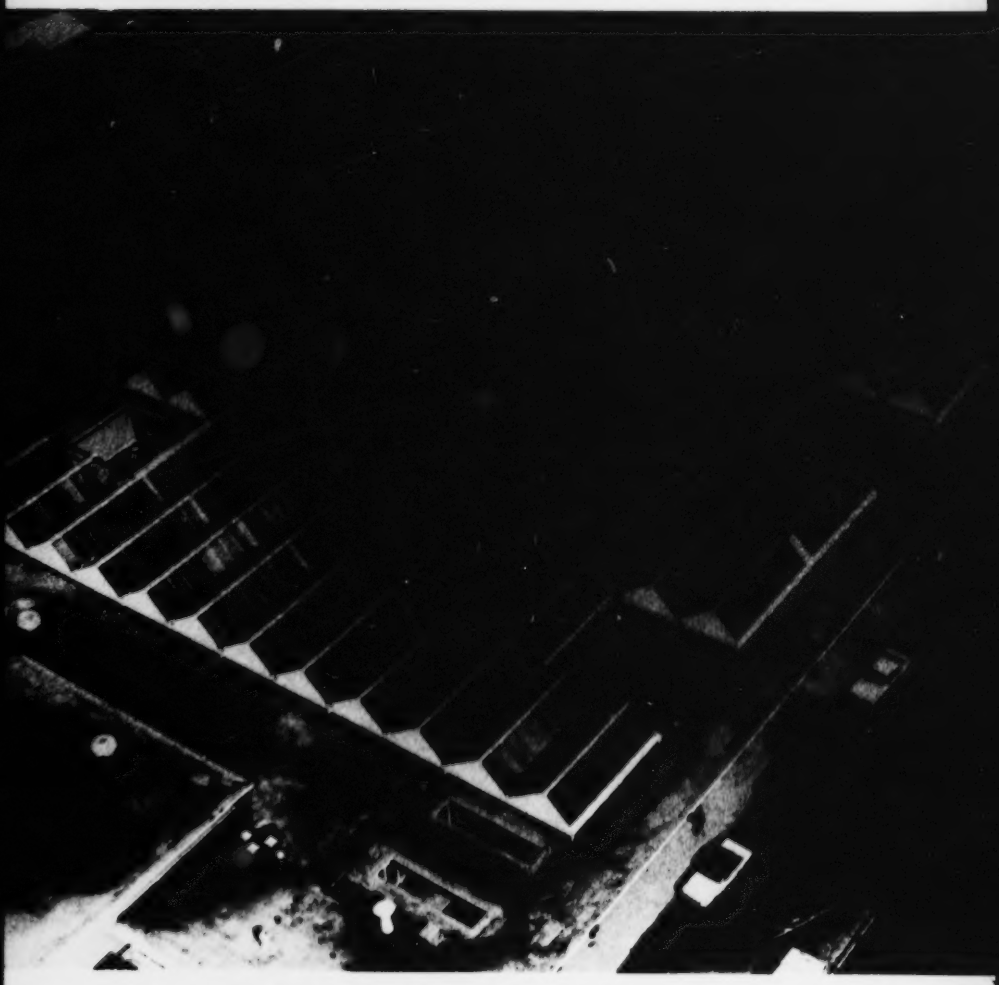
The high cost of fossil fuels—fuel oil, coal, and natural gas—led many homeowners in areas where wood was abundant to turn to wood-burning stoves and furnaces as a means of heating their homes. But fossil fuels remain the chief source of heat for homes and for generating the steam that turns the turbines in electric power plants.

HEATING YOUR HOME AND SCHOOL

If you could turn up the thermostat in your home or school, raise the air temperature to a comfortable level, and then turn off the heat for the rest of the heating season, no one would complain about heating costs. Unfortunately, that's not the way it works.

When air in a building is heated, the air molecules acquire more kinetic energy. These fast moving particles bump into the molecules on the surface of the walls of the building and transfer some of their kinetic energy to them. These molecules, in turn, transfer kinetic energy to

OPPOSITE: NOTE THE SOLAR PANELS ON THE ROOFS OF THESE HOMES IN GREENBELT, MARYLAND.
ABOVE: THE BROOKHAVEN HOUSE IN UPTON, NEW YORK, WAS DESIGNED TO DEMONSTRATE PASSIVE SOLAR HEATING AND THERMAL STORAGE FOR HOMES BUILT IN THE NORTHEAST. HERE YOU SEE A WOOD-BURNING STOVE ELEVATED FROM THE FLOOR AND SET IN FRONT OF A BRICK WALL. THE PLATFORM CHANNELS HEAT FROM THE BOTTOM OF THE STOVE TO THE AIR BELOW INSTEAD OF INTO THE FLOOR; WHEN THE WARM AIR LEAVES THE SPACE, IT WILL RISE AND CIRCULATE IN THE ROOM. THE BRICK WALL WILL ABSORB AND RADIATE HEAT.



SOLAR HEATING AND COOLING SYSTEM AT THE
GEORGE A. TOWNS ELEMENTARY SCHOOL IN ATLANTA, GEORGIA.
REFLECTORS ON THE BACK SLOPE OF THE COLLECTORS
ALLOW THE COLLECTORS TO ABSORB ENERGY FROM
BOTH DIRECT AND REFLECTED SUNLIGHT.

molecules deeper in the wall. Eventually, kinetic energy is transferred by the molecules on the outer surface of the walls to less energetic molecules in the cold air outside the building. This transfer of energy from molecule to molecule through collisions is called *conduction*, and we say heat "flows" from warm objects to colder ones.

Infiltration of cold air into a building through cracks around windows, doors, and sills forces warm air out through other cracks. This type of heat transfer is called *convection*. There are also convection currents within a building as warm air rises over denser, cooler air; however, convection heat losses through ceilings, walls, and floors are generally small because the small air spaces within these structures break up convection currents.

Heat, like light, is transferred from sun to earth by radiation. Since space is virtually a vacuum, there is no way the sun's heat could reach us through conduction or convection. You have probably sensed radiant heat entering your body from a fireplace or from the sun when you stood in sunlight while wearing dark clothing. If you stand near a large window on a cold, cloudy day, you will probably feel cold as heat radiates from your body to the cold window.

The two major causes of heat loss from a building are conduction and infiltration. Conduction heat losses can be reduced by placing insulating materials in walls, ceilings, and floors. Sealing the cracks that allow cold air to enter a building will eliminate the drafts (infiltration) that drive warm air from a building and allow cold air to enter.

The projects that follow will help you to determine the factors involved in conductive heat losses.

*PROJECT 11: Conductive heat losses and surface area

Your own experience has probably convinced you that surface area is related to the rate at which heat is lost to the surroundings. If you wake up feeling cold while a bliz-

zard rages outside, you feel warmer when you curl up into a "ball." On the other hand (or season), you feel cooler on a hot, humid summer night if you stretch out, exposing as much of your body's surface area as possible to the air.

Establishing the relationship between conductive heat loss and surface area is not easy because other factors—insulation, temperature differences, and time—affect the rate of heat flow. As with any experiment, you must be careful to test only one factor at a time.

You can investigate the effect of surface area on conductive heat loss by making two pieces of ice that have the *same* volume but different surface areas. Pour 30 to 50 ml of water into containers that have different shapes. You might use a cubic container and the top from a large plastic container to make a pancake-shaped ice "cake." Or use two cylindrical containers with very different diameters. Because the ice cakes are made with the same volume of water, the same amount of heat will be required to melt each of them. Since 80 cal, 334 J, or 0.31 Btu are needed to melt 1 g of ice, you can easily figure out how much heat is required to melt whatever mass of ice is changed to liquid.

Once the ice has frozen thoroughly, fill a bucket or large container with water. Be sure to use a lot of water so that its temperature will not change significantly as the ice melts. After all, the greater the temperature difference between water and ice, the faster the ice will melt.

Before you add one of the ice cakes to the water, measure its dimensions (so that later you can determine its surface area). Then quickly dry and weigh it. Drop the ice cake into the water. Stir the water constantly so that the surface of the ice will be in contact with the warm water, not with its own meltwater. After 10 s, remove the ice from the water. Quickly dry it and reweigh it. Repeat the procedure using the second ice cake, which has a different surface area.

What mass of each of the ice cakes melted in 10 s? How much heat was transferred to one of the ice cakes

per second? How much heat per second was transferred to the other piece of ice? What was the surface area of each piece of ice?

Compare the two ratios:

$$\frac{\text{Heat flow into ice cake \#1 in 1 s}}{\text{Heat flow into ice cake \#2 in 1 s}}$$

and

$$\frac{\text{Area of ice cake \#1}}{\text{Area of ice cake \#2}}$$

What do these ratios tell you about the relationship between heat flow and surface area? Why can't you simply wait until all the ice melts and then calculate the heat flow per second? How will the heating costs of a house with a large surface area compare with one with a small area if all other factors are the same?

*PROJECT 12: Heat loss and temperature difference

From experience you know that the rate of heat flow from your body depends on the temperature of your surroundings. Step outside on a cold day and you lose heat so rapidly that you'll soon begin to shiver. On a hot summer day, you may feel uncomfortably warm even if you're clad only in light clothing because the rate of heat flow from your skin is so slow.

To find out how the difference in temperature between a warm body and a cool one affect the flow of heat, add 100 ml of hot water to each of two identical cups. The temperature of the water in both cups should be the same. Put one of the cups in a warm room; put the other one in a cold place such as a refrigerator or in a protected place outside if it is cold weather. Record the temperature of the water in each container at 1-min intervals. In which place does heat flow more rapidly from the hot water?

To obtain a better understanding of how heat flow is related to temperature difference, plot graphs of temperature versus time for each cup of water on the same set of axes. Plot temperature on the vertical axis and time on the horizontal axis. In which environment does the water cool faster? From the slope (rise/run) of either graph you can tell when the water is cooling fastest. How does the difference in temperature between the water and its environment affect heat flow?

By drawing lines tangent to a carefully drawn graph of temperature versus time for hot water cooling in a cool environment, you can measure the rate of heat loss at various temperatures. The slope of the line will give you the change in temperature per unit of time. From the mass of water that is cooling and the temperature change, you can determine the rate at which heat is being lost at the temperature where the line is tangent to the curve (see Figure 2). Repeat this process at a variety of temperatures and note the temperature difference between the water and its cooler surroundings for each temperature. Then plot a graph of the rate of heat loss versus the difference in temperature between the water and its surroundings. How is the rate of heat loss related to the temperature difference between the warm water and the cooler air around it?

***PROJECT 13:**
Designing another method to determine how heat loss is related to the difference in temperature between hot and cold bodies

Design an experiment, using identical ice cakes and large volumes of water at different temperatures, to see how the rate of melting is related to the temperature difference between the ice and the water in which it melts. Since the melting rate is determined by the rate at which heat flows into the ice, you are really finding how the rate of heat flow is related to the temperature difference

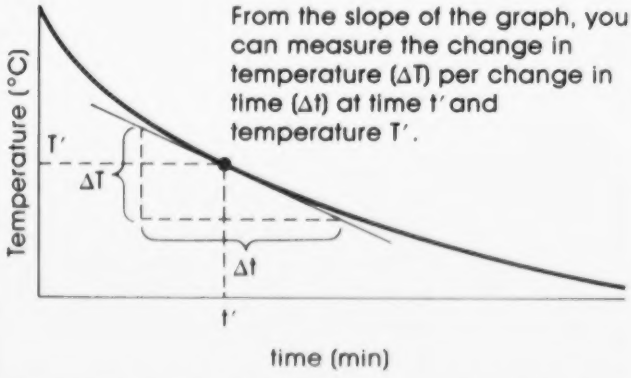

From the slope of the graph, you can measure the change in temperature (ΔT) per change in time (Δt) at time t′ and temperature T′.
Temperature (°C)
T′
ΔT
Δt
t′
time (min)

Figure 2 Graph of temperature against time for a cooling substance

between ice and its warmer surroundings. What do you find? Do your results agree with your findings in Project 12?

INSULATION AND R VALUES

In Projects 11, 12, and 13 you found that heat losses are proportional to temperature difference and surface area. It's evident that heat losses are also proportional to the time that heat flows. After all, if the temperature difference and the surface area of a warm body remain constant relative to some cooler surroundings, then in twice the time, twice as much heat will be transferred from the warm body. The only other factor involved in heat loss is the conductivity of the material that may lie

between the warm body and its cooler surroundings. By "conductivity" we mean the rate at which heat flows through the material. Conductivity is measured by the amount of heat that flows through a unit area per unit time for each degree of temperature difference between the warm and cold side of the conducting material.

For example, suppose a warm air space surrounded by 10 sq ft of ¾-in wood sheathing loses 100 Btu of heat per hour when the temperature of the enclosed air is 10°F warmer than the air outside the wood. The conductivity of the wood is 100 Btu per hour per 10 sq ft per 10°F, or 1.0 Btu/h/ft^2/°F. When fiberboard is used instead of sheathing, the heat losses drop to 50 Btu and so the conductivity, or *U value*, becomes 0.5 Btu/h/ft^2/°F.

Homeowners and builders want insulating materials in the walls of their houses, that is, substances that do not conduct heat well. Consequently, insulating materials are rated according to their ability to resist the flow of heat. A material's ability to resist the conduction of heat is measured in terms of R value, which is just the inverse of conductivity. If we represent conductivity by the symbol U, then the R value of a material is defined to be:

$$R = 1/U$$

The conductivity of the fiberboard above was 0.5 Btu/h/ft^2/°F. Its R value would be:

$$R = 1/U = 1/0.5 = 2 \text{ ft}^2\cdot\text{h}\cdot{}^\circ\text{F/Btu}$$

R values are just U values turned upside down so that consumers can deal with numbers greater than 1. The larger the R value of a material, the better its insulating quality.

PROJECT 14:
R Value

To measure the R value of a cardboard box, put a 100-W light bulb and socket in the center of a large cardboard box. Seal the box with tape and place it on several small

blocks so that the entire surface of the box is exposed to the cooler air around it. Push the bulb of a thermometer through a small hole about halfway up the side of the box so you can measure the average temperature inside the box. Another thermometer can be used to measure the temperature outside the box.

Plug in the light bulb. When the temperature inside the box becomes constant, we can assume that heat losses from the box equal the rate at which heat is being generated by the bulb inside. We know the heat generated inside is 100 J/s because it's a 100-W bulb. Using this information, the area of the box, the temperatures inside and outside the box, and a time interval of 1s, determine the R value of the cardboard.

Now that you know the R value of a certain thickness of cardboard, you can determine the R value of other materials by comparing the rate at which they lose heat when compared to an equal area of cardboard. What is the R value of insulated coffee cups? What about the R values of other insulating materials such as fiberglass, rock wool, cellulose, vermiculite, paper, and wood? How is R value related to the thickness of a material?

How do the R values that you have measured compare with those found in books on home energy or at a lumber store?

DEGREE-DAYS

To predict the cost of heating a home for a year, heating engineers have developed the idea of degree-days (DD), which are based on degrees Fahrenheit. As long as the outside temperature is greater than 65°F, a building does not have to be heated. But when the outside temperature drops below 65°F, heating systems go to work. To determine the number of degree-days in one day, find the average temperature for the day in degrees Fahrenheit, subtract it from 65 and multiply by 1 day.

Suppose the average temperature for a certain day is 35°F, the degree days for that day would be 30°F × 1 day, that is, 30 DD. If the temperature for the next day

averages 50°F, then the degree-days for that day would be 15 DD. The sum of the degree-days for the two days would be 45 DD.

Since heat losses are proportional to the temperature difference between inside and outside air, a home will require twice as much heating fuel on a day when there are 30 DD as on a day when there are 15 DD. In a city such as Pittsburgh, Pennsylvania, where there are 5,987 DD in an average year, a homeowner will require about twice as much heating fuel for the same house as will a resident of Atlanta, Georgia, where there are only 2,961 DD in a year.

You can find the number of degree-days per heating season in your vicinity by reading the weather column in your local newspaper or by calling a fuel supply company. If you multiply the number of degree-days by 24, you will have the number of degree-hours for your heating season.

You have seen that heat losses are proportional to time, surface area, temperature difference between inside and outside air, and to the conductivity of the materials that enclose the warm air. Because a degree-day takes into account both the difference in temperature between inside and outside air and the time, and since conductivity, in Btu/h/ft^2/°F, is the inverse of R values, we can calculate the heat losses from a building for the entire season using the following formula:

$$\text{Heat losses} = 1/R \times \text{surface area} \times 24\ \text{h} \times \text{DD}$$

For example, a house with 2,000 sq ft of surface and an R value of 10 in a 4,000 DD area would lose:

$$1/10 \times 2{,}000 \times 24 \times 4{,}000 = 19{,}000{,}000\ \text{Btu of heat}$$

Of course, a house has walls, windows, ceilings, and often a basement, all with different R values, so it is usually necessary to consider conductive heat losses through all of these surfaces separately. By adding the heat losses through each surface, one can determine the total heat lost from the building in one heating season.

PROJECT 15:
Determining the conductive heat losses from your home or school

Measure the surface area of the walls, windows, and ceilings of your home or school. Using the degree-days for your town and the table of R values found in Appendix 1 or in similar tables that you can obtain from a lumberyard, determine the conductive heat losses from the building for one heating season.

INFILTRATION

Heat losses due to infiltration are not as easy to measure as conductive heat losses, but reasonable approximations can be made if you know the volume of the building, the number of air turnovers per hour, and the temperature difference between inside and outside air.

The volume of the air in a building multiplied by 0.018 Btu/ft^3/°F, which is the heat required to raise the temperature of 1 cu ft of air through 1°F, gives the heat required to warm the air through a degree. If this figure is then multiplied by the number of air turnovers per hour, the number of hours in a day, and the number of degree-days in a year, you can find the heat required to warm the air that enters the building by infiltration. The formula below gives the heat losses associated with infiltration for one heating season.

$$\text{Heat} = \text{Volume} \times 0.018 \times N \times 24 \times DD$$

(N is the number of air turnovers per hour.)

The volume of air in a buildling is easy to find; all you need do is measure the volume of the air space within the structure. But how do you find N, the number of air turnovers per hour? This is not an easy task, but Table 2 will allow you to make a reasonable estimate of N. Simply average the four values obtained. You may decide to give ratings between 1 and 2 or 2 and 3; you might even give ratings of 0.5 if the seals are extremely tight. For

TABLE 2
Determining air turnovers per hour

Part of the building	*1 air turnover per hour if*	*2 air turnovers per hour if*	*3 air turnovers per hour if*
Basement OR	Tight, no cracks. Sills, windows, doors all caulked and sealed.	Some cracks, loose windows and doors.	Big cracks, poorly sealed windows and doors.
Crawl space	Plywood floor, no trapdoor. Utility pipes entering building well sealed.	Tongue and groove floor, tight. Seals around trapdoor and utility pipes entering house.	Board floor. Loose fit on utility pipes entering house.
Windows	Tight fitting, weatherstripped, and storm windows.	Tight fitting, weatherstripped, but no storm windows.	Loose windows, no storm windows, no weather stripping.
Doors	Tight-fitting doors and storm door, weather stripping.	Loose storm doors. Poor fit on doors, no weather stripping.	No storm doors, doors fit poorly, no weather stripping.
Walls	Good caulking around all windows and doors. Building paper under siding.	Loose caulking, needs painting.	Cracks around doors and windows. No building paper under siding.

example, if windows are tight and have double glazing, and there are storm windows as well, the windows would merit a 0.5 rating rather than 1.0. Extremely poor windows might receive a rating of 4.

PROJECT 16:
Finding the heat losses that result from infiltration in your home or school

Determine the volume of air in your home or school. Then estimate the number of air turnovers per hour. Finally, determine the heat losses from your home or school that result from infiltration.

PROJECT 17:
Annual heating costs

Using the heat losses due to conduction and infiltration that you found in Projects 15 and 16, determine the total annual heat losses from your home or school.

Table 3 on the following page will enable you to convert heat in kilowatt-hours (kWh) of electricity, gallons of fuel oil, cords of wood, cubic feet of natural gas, and tons of coal to an equivalent number of Btu's. Use the table to figure out how much energy is required to heat the building for a year. Then, after you find the cost of a unit of the type of fuel used to heat the building, determine how much it costs to heat the building for one year.

PROJECT 18:
Ice cube keeping

Now that you are an expert on heat losses and insulation, put your knowledge to a test. Design some "ice cube keepers," spaces in which ice cubes can be kept for long periods of time without melting even though they are in a room temperature environment. See if you can predict which of a variety of keepers will be most effective.

TABLE 3
Fuel efficiencies
and conversion to Btu's

Unit of heat	*Equivalent No. of Btu's*	*Approximate Efficiency of fuel*
1 kilowatt-hour	3,413	100%
1 ton of coal	26,200,000	60%
1 gallon, #2 fuel oil	138,800	70%
1 cubic foot of natural gas	1,031	70%
1 cord of wood	15,000,000	50%

4

ELECTRICAL ENERGY

If you've ever turned on an electric stove or used an electric toaster in preparing breakfast, you know that electricity can be converted to heat. You've also probably seen electric motors lift weights, turn drill bits, spin lawn mower blades, or do other forms of work, so you have good evidence that electricity is a form of energy. But where does electrical energy come from?

SOURCES OF ELECTRICITY

When an object such as a rubber rod is rubbed with a woolen cloth, both rod and cloth become electrified. If you take off a woolen sweater in a dark room during the winter, you see and hear the electric sparks produced when the positive and negative charges attract each other and combine. The charges that reside on surfaces that have been rubbed together constitute static electricity—electric charges at rest.

If an object that holds an excess of positive charge is connected by a wire to an object with an excess of negative charge, the negative charge (electrons) will move

along the wire to the positive charge because opposite charges attract one another. Moving charge constitutes an electric current, and electric current generally comes, not from static charge, but from one of two sources—batteries or electric generators.

The chemical energy stored in batteries can be changed to electrical energy when the charge at one electrode of the battery flows to the opposite charge at the other electrode.

In an electric generator, when a coil of wire is rotated in a magnetic field, electric charges are pushed along the wires. Through connections at the ends of the coil, charge can flow from one end of the coil through a circuit to the other end of the coil. This flow of charge is an electric current, just like the one that travels from one electrode of a battery to the other. The only difference is that with a generator, depending on how the ends of the coil are connected to brushes, the current can be made to flow periodically, first in one direction and then in the other (an alternating current), or continually in the same direction (a direct current). With batteries the current is always a direct current.

MEASURING ELECTRICITY

Electric meters, such as ammeters and voltmeters, are used to measure electricity. Ammeters measure electric current. If you examine an ammeter, you will see that the units on the meter are amperes (A). Because the ammeter needle remains steady when current flows, the meter must be measuring the rate at which charge flows. It does not measure charge. If it did, the meter reading would start at zero and rise steadily as more charge flowed through the ammeter.

GENERATORS AT THE HOOVER DAM POWERPLANT.

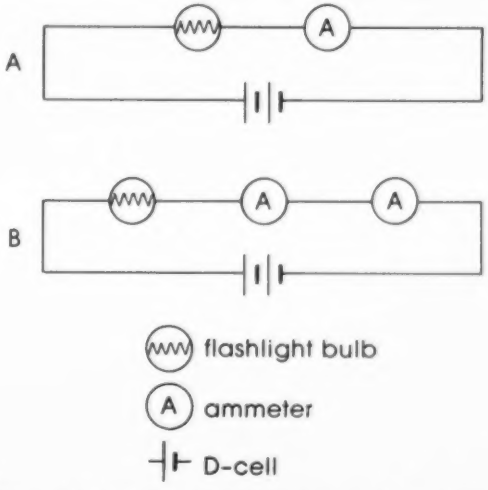


Figure 3 Ammeters, alone and in series

PROJECT 19:
Ammeters in series and in parallel

Ideally, instruments used to make measurements should have no effect on what they measure. A ruler, for example, has no effect on the length of the object measured; however, a thermometer with a large mass might very well change the temperature of a small volume of water.

To see if an ammeter has a significant effect on the current it measures, set up the circuit shown in Figure 3A. If possible, use ammeters with a 0- to 1.0-A scale. If the current through the bulb is too small to measure accurately, add another D-cell to your battery, but don't let the circuit operate for very long; it could wear down the D-cells quite rapidly.

Find the current through the ammeter. Substitute a second similar ammeter for the first one. How closely do the meter readings agree? Now connect the two ammeters in series as shown in Figure 3B. Does the addition of an ammeter to a circuit have a significant effect on the current?

Substitute a voltmeter for one of the ammeters. Does a voltmeter have any effect on the current?

Using two bulbs and several D-cells, set up the parallel circuit shown in Figure 4. Use an ammeter to find the current through each bulb by placing the ammeter (or two identical ammeters, if you have them) at points x_1 and x_2. Now see if you can predict the current at points y_1 and y_2. How do you explain your results?

PROJECT 20:
Ammeters, clocks, and charges

If an ammeter measures the rate of charge flow or electric current in amperes, then the product of current and time (in seconds) should give us charge in units of ampere-seconds (A-s). But is there any way to be sure that the product of current and time is really a measurement of charge?

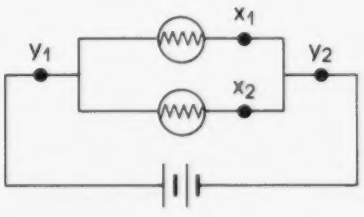


Figure 4 Bulbs in parallel

Certainty in science is hard to come by, but we become increasingly certain if an idea is confirmed in a number of different ways. During the electrolysis (decomposition by electricity) of water, hydrogen gas is released at the electrode attached to the negative pole of the battery while oxygen is released at the other (positive) electrode. Since these gases are released only when the circuit is connected, we believe the flow of charge causes water to be decomposed into its elements. Therefore, it seems reasonable to believe that the mass (or volume under stable conditions) of these gases is directly related to the charge that has flowed through the circuit.

Do this experiment under supervision and wear your safety goggles.

To see if measuring charge as the product of current and time makes sense, set up the circuit shown in Figure 5. Note that the graduated cylinder is over the electrode

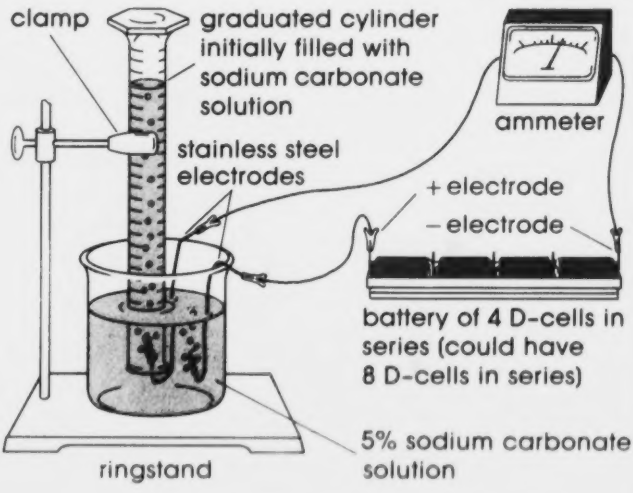


Figure 5 Measuring charge in two ways

connected to the negative pole of the battery. Thus, the gas collected in the cylinder will be hydrogen, which has twice the volume of the oxygen produced at the positive electrode. **Do not collect both gases. A mixture of hydrogen and oxygen is dangerous because a small spark could cause the gases to explode, sending broken glass in all directions.**

The solution in the beaker and cylinder is a 5% solution of sodium carbonate monohydrate ($NaCO_3 \cdot H_2O$). To make the solution, add 25 g of sodium carbonate to 500 ml of water.

Connect the circuit to the battery. Record the current, time, and volume of hydrogen collected at 60-s intervals. Let the circuit run until about 30–40 ml of gas have accumulated before disconnecting it.

For each 60-s period calculate the charge, in A-s, that flowed during that time. Then, by addition, make a running record of the total charge that flowed after 120 s, 180 s, 240 s, etc. The sample data table—Table 4—below will help you to set up yours.

TABLE 4
Data Table

Time (s)	Volume of gas (ml)	current (A)	charge/ 60 s (A-s)	Total charge (A-s)
60	3.0	0.40	24	24
120	6.0	0.40	24	48
180	9.2	0.42	25	76
240	12.5	0.44	26	106

Using your data, plot a graph of total charge, measured in ampere-seconds, on the vertical axis versus total charge, measured in milliliters of hydrogen, on the horizontal axis. What can you conclude from this graph? Do you have increasing evidence that charge can be measured by taking the product of current and time?

From the slope of the graph, determine the number of ampere-seconds equivalent to 1 ml of hydrogen. What volume of hydrogen is equivalent to 1 A-s?

If you know the barometric pressure and temperature of the surroundings, determine the density of the hydrogen gas that you collected. The density of hydrogen at 0°C and 1 atmosphere of pressure is 0.0899 g/liter or 8.99×10^{-5} g/ml. What mass of hydrogen is produced by 1 A-s of charge?

*PROJECT 21: What does a voltmeter measure?

You've probably heard that a voltmeter measures voltage, or potential difference. But what does that mean? To find out, connect a voltmeter with a 0–15-V scale in parallel with an electric heater and ammeter as shown in Figure 6.

A 20-ohm resistor can serve as the heater. It is placed in 50 g of cold water in an insulated cup. The temperature of the water should be about 2–3°C below room temperature to compensate for heat losses when the water temperature rises above that of the room.

Record the temperature of the cool water in the insulated cup to the nearest 0.10°C, if possible. Set the variable voltage source so that a current of approximately 0.7 A flows through the heater immersed in water for a period of 2 min. Record the voltmeter and ammeter readings as the current flows. After the run is completed, stir the water thoroughly and record its final temperature.

What was the change in temperature of the water? How much heat, in calories, was produced by the electricity?

In succeeding runs, starting with fresh cool water each time, let a current of about 0.6 A flow for 2.5 min, then 0.5 A for 3.5 min, and, finally, 0.4 A for 5 min. Record the voltage, current, time, and temperature change of the water for each run.

When you have collected all the data, calculate the heat delivered, in calories, and the charge, in A-s, for each run. Then plot a graph of *heat per charge* on the

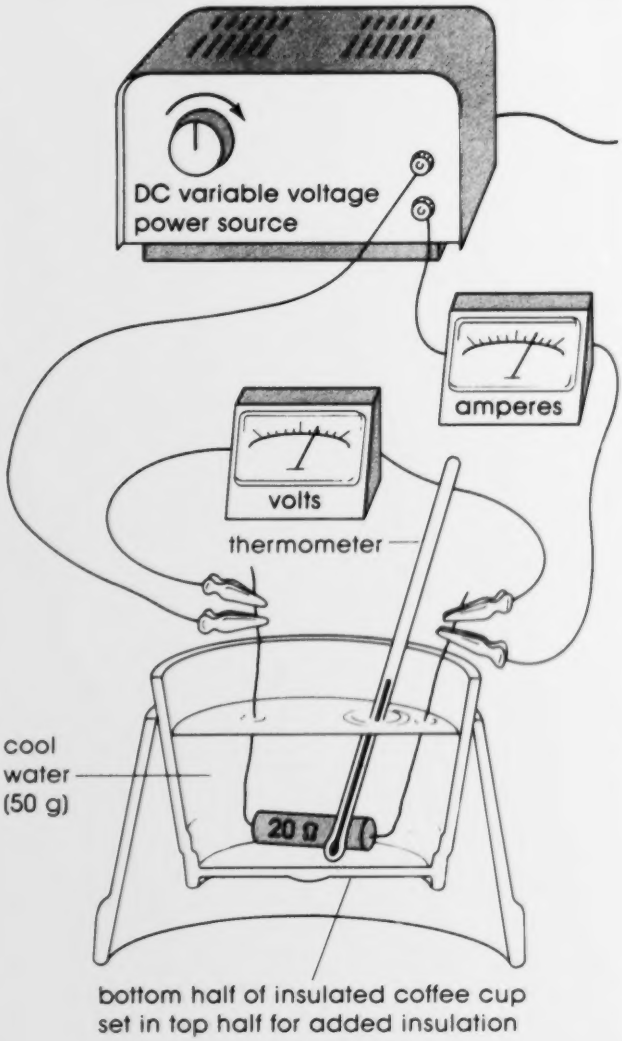


Figure 6 What does a voltmeter measure?

vertical axis versus the voltmeter reading, in volts. What does the graph tell you? What does a voltmeter measure?

Write an equation relating heat, current, time, and voltage.

The product of voltage × current × time is called electric work and is measured in joules. If you measure heat in joules, write the equation relating heat, current, time, and voltage. How many joules are equal to 1 cal?

Notice that you may now write 1 V = 1 J/A-s.

Charge is also measured in another unit called a coulomb (C). One coulomb is the same amount of charge as 1 A-s; hence, you can also write:

$$1\ V = 1\ J/C$$

PROJECT 22:
Meters in your home and school

Most of the electricity used in homes and commerce is purchased from a utility company. To determine how much to charge each month, the utility company puts a meter in the line leading to each building for which a bill is rendered.

If you can find the place where the electric power line enters your house, apartment, or school, it will be connected to a meter. Current flowing through the meter causes the disk inside the meter to turn. Through a series of gears, the spinning disk turns the meter dials and thus gives a reading of the electrical energy entering the building. The dial on the right records kilowatt-hours, the next dial indicates tens of kilowatt-hours, the next, hundreds of kilowatt-hours, and so on.

As you probably know, a watt is a unit of power equal to 1 J/s. An ampere of current is a flow of 1 C/s. Hence, you may write:

$$1\ C/s \times 1\ J/C = 1\ J/s \text{ or } 1\ W$$

A kilowatt is 1000 J/s, and an hour is equal to 3,600 s; therefore, a kWh is: 1,000 J/s × 3,600 s = 3,600,000 J.

The power ratings on various appliances, when multiplied by the time they are used, will indicate how much electrical energy these devices require. For example, a 100-W light bulb when turned on for 1 h will require: 0.10 kW × 1.0 h = 0.10 kWh. If the power company charges you $0.10 per kilowatt-hour, operating the light bulb for 1 h will cost 0.10 kWh × $0.10/kWh = $0.01, or one cent.

Make a survey of the electrical appliances in your home or school. How many hours or minutes per day does each one operate? How much energy does each appliance require over a year's time? On the back of your family's or school's electric bill you will find the cost of a kilowatt-hour. Use this figure to determine the cost of operating each appliance for one year.

THE DIRECTION OF CURRENT FLOW

The fact that electric current disappears when a circuit is broken at any point is good evidence to support the idea that charge flows all the way around a circuit. But which way does charge flow? Does positive charge flow from the positive to the negative end of a battery? Or does negative charge flow in the opposite direction? Or does charge of both signs flow in both directions?

Physicists *defined* the direction of electric current to be the direction that positive charge would flow in a circuit long before the actual direction was determined. That definition still holds, and, as you will see, that definition is sometimes valid.

PROJECT 23: A vacuum tube and the direction of charge flow

Vacuum tubes were common in electronic devices prior to the development of solid state physics. You can buy

one at a radio store or from a mail order supplier (see your science teacher), or you can dismantle old radios or other devices, which might have such tubes. Tube type 12D4 works well, but you can also use types 6AX4 or 6W4G. These tubes, which are well evacuated, will conduct electric charge under certain conditions.

Set up the circuit shown in Figure 7A. With the 12D4 tube inverted to reveal its pins as shown in Figure 7B, the connections to the heater and to the cathode and plate can be made using alligator clips.

You will note that there are really two circuits. The circuit containing the heater consists of a 12-V battery or a DC power source connected to a heating wire coiled within the cathode. This circuit is used solely to warm the cathode. The second circuit consists of a 12-V battery or DC power source with its positive and negative electrodes connected to either the cathode or the plate within the vacuum tube. It also contains an ammeter (0–1 A) to detect any current that might flow between the cathode and plate.

With the heater circuit disconnected, connect the positive lead from the battery to the plate and the negative lead to the cathode. Is there any current? Reverse the leads. Does current flow now?

Now connect the heater circuit so that the cathode is hot. You should be able to see a red glow coming from the cathode. Once the cathode is hot, connect the positive lead from the battery in the other circuit to the plate. Connect the negative end of this battery to the cathode. Is there any evidence that charge is flowing across the vacuum? What happens if you disconnect the cathode heater?

Repeat the experiment, but this time connect the cathode to the positive end of the battery and the plate to the negative end. What do you find now?

From your observations, what conditions are required for charge to flow across the vacuum between cathode and plate? Can you offer an explanation as to why there is a current given the required conditions but no current otherwise?

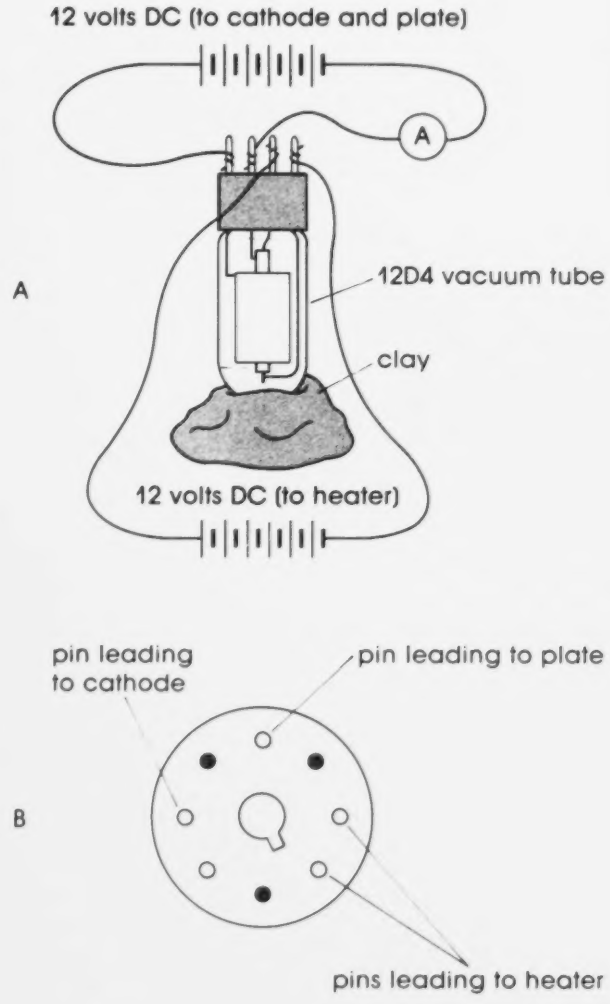


Figure 7 Connections to a vacuum tube

ELECTROLYSIS, ATOM COUNTING, AND THE CHARGE PER ATOM

Historically, scientists were able to determine the relative charge associated with atoms of different elements before the actual masses of the atoms were known. Today the actual masses of all the atoms have been determined with good accuracy. You can easily find the mass of an atom of any element. Simply divide the atomic mass of the element, in atomic mass units (amu), by 6.02×10^{23}. The mass of the atom will be in grams.

Knowing the mass of a single atom, you can calculate how many atoms are plated out or dissolved during electrolysis. If you also know the total charge involved in bringing about these mass changes, you will be able to determine the charge associated with each atom as well.

*PROJECT 24: Electrolysis and the charge per atom

If you did Project 20, you may have found that 1.04×10^{-5} g of hydrogen are released for every ampere-second of charge that flows during the electrolysis of water. Since the mass of a hydrogen atom is 1.66×10^{-24} g, 1 A-s of charge is associated with 6.27×10^{18} atoms of hydrogen. This means that the charge required to release one atom of hydrogen during electrolysis is:

$$1.00 \text{ A-s}/6.27 \times 10^{18} = 1.60 \times 10^{-19} \text{ A-s/atom.}$$

Because one atom of oxygen is released for every two atoms of hydrogen during the electrolysis of water, the charge required to release one atom of oxygen must be just twice that for hydrogen or 3.20×10^{-19} A-s.

To find the charge associated with one atom of zinc, place a pair of zinc electrodes in a 1.0 M solution of zinc sulfate ($ZnSO_4$) as shown in Figure 8.

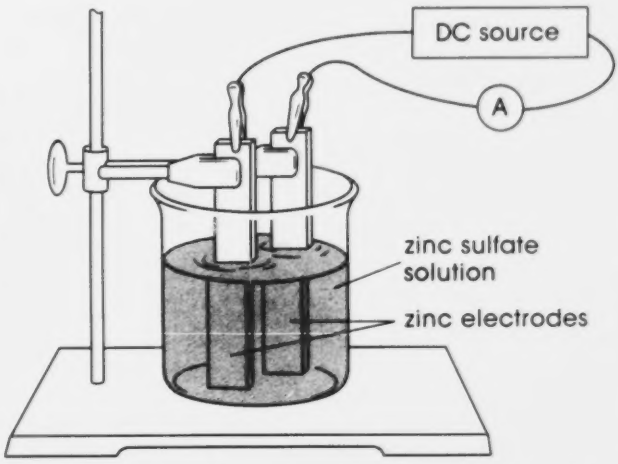


Figure 8 The charge associated with one atom of zinc

You can make the solution by dissolving 287 g of $ZnSO_4 \cdot 7H_20$ in distilled water and then diluting to 1 liter with water. The electrodes can be made by cutting 2-by-4-in (5 cm × 10 cm) pieces from a sheet of zinc.

Clean the electrodes with steel wool or a scouring pad and then weigh each electrode to the nearest 0.01 g. Using D-cells or a low-voltage DC power source, let a current of about 1.0 A run for approximately 30 min. Record the current every minute.

After disconnecting the circuit, gently rinse and dry the electrodes by dipping them in a beaker of water and then patting them dry with a paper towel. To insure thorough drying, place the electrodes under a heat lamp for several minutes. Then weigh the electrodes. After several minutes weigh them again to be sure that they were thoroughly dry.

Find the average current and multiply it by the total time in seconds. This will give you the total charge that flowed through the circuit.

Which electrode gained mass? Which electrode lost mass? How do the mass changes for the electrodes compare? Can you explain what is happening during the electrolysis of zinc sulfate? How many atoms of zinc came out of, or went into, solution at each electrode. What charge, in ampere-seconds (or coulombs), is associated with one atom of zinc?

Try to predict the mass changes that will occur at each electrode if you operate the cell for different times at about the same current.

*PROJECT 25: The charge per atom for other elements

You can determine the charge associated with atoms of other elements in a similar manner.

For lead, use electrodes of the same size cut from a sheet of lead. The solution can be prepared by dissolving 165 g of lead nitrate ($Pb(NO_3)_2$) and 1 g of gelatin in enough warm, distilled water to make a liter of solution. (Somehow, the gelatin makes the lead stick better to the negative electrode.) To avoid the growth of "trees" during electrolysis, bend the electrodes into a convex shape by gently pressing them against the sides of a beaker. Then set them in the solution, after weighing, with their edges as far apart as possible (convex surfaces facing each other).

For copper, use similar size electrodes cut from 20-mesh copper gauze. A solution of copper sulfate can be prepared by dissolving 200 g of hydrated copper sulfate ($CuSO_4 \cdot 5H_2O$) in enough water to make about 0.9 liter of solution. Add 75 ml of 6 M sulfuric acid (**carefull**), stir, and dilute with distilled water to 1 liter.

This experiment involves the use of potentially dangerous chemicals. Be sure to wear safety goggles and

a lab apron and to work under the supervision of a knowledgeable adult.

ELECTRIC CELLS

One of the simplest and oldest electric cells is the Daniell cell. It was invented in 1836 by John F. Daniell. It was the first cell that could be depended upon to give a steady current for long periods, and was used extensively in the early days of telegraphy to send electric signals along wires.

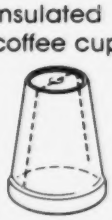
*PROJECT 26: Building and using a Daniell cell

Figure 9 shows you how to build a simple Daniell cell using a polystyrene cup, parchment paper, and glue. Once the container is built and the glue has dried, electrodes of copper and zinc may be placed on opposite sides of the parchment barrier and secured with clamps. The bottoms of both electrodes should be just above the bottoms of the cups. Solutions of zinc sulfate and copper sulfate, prepared in Projects 24 and 25, will be poured into the compartments containing the zinc and copper electrodes to provide electrolytes for the cell. Minimize mixing of the solutions due to diffusion through the barrier by adding the solutions to the cell when you are ready to measure current, voltage, temperature, and time.

Wear safety goggles and work under supervision.

Pour copper sulfate solution into the side of the cup that contains the copper electrode. Pour zinc sulfate into the other side. Measure the temperature of each solution, then connect a voltmeter to the electrodes. What is the potential difference (voltage) across this cell? Connect a sensitive ammeter to the electrodes so it is in parallel with the voltmeter. Move the electrodes closer together, if necessary, to obtain a current of at least 0.5 A.

A

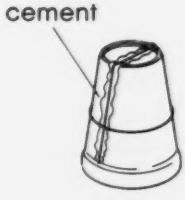


With a razor blade carefully cut a slit along the dotted lines as shown in the drawing.

B

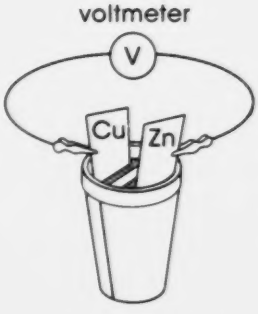
Slide a piece of parchment paper into the slit as shown.

C



Carefully trim the parchment paper to fit the cup. Seal with Duco cement and use a rubber band to hold cup firmly against paper until cement dries.

D



When dry, a zinc electrode and $ZnSO_4$ solution can be placed in one side and copper electrode and $CuSO_4$ solution in the other.

Figure 9 Building a Daniell cell

What happens to the voltmeter reading when current flows? What happens to the temperature of the solutions as time passes? Record the current every minute for at least 20 min.

Disconnect the circuit, rinse and dry both electrodes as described in Project 24, and determine the change in mass of each. Which electrode gained mass? Which one lost mass? Determine the total charge that flowed in the circuit.

From your measurements of charge and mass, calculate the number of atoms of each element that plated out or dissolved. Determine the charge associated with one atom of zinc and one atom of copper. How do your results of charge per atom compare with those found in Projects 24 and 25?

From what you have seen and measured in this experiment, try to devise a model to explain the flow of charge in this circuit. Remember, only electrons can move along wires, and, in the solutions, both copper and zinc ions carry positive charge. Sulfate ions, which are also free to move in solution, provide the negative charge needed to balance the charges on the positive ions.

*PROJECT 27: More experiments with a Daniell cell

Repeat the experiment you did in Project 26, but this time watch what happens to the voltmeter reading as the current through the circuit changes. To change the current, simply change the distance between the electrodes. What happens to the voltage as the current increases?

From Project 21 you learned that a voltmeter measures energy per charge. A voltmeter reading of 10 V means 10 J/C are being delivered to the part of the circuit between the leads of the voltmeter. Can you explain why the voltage decreases as the current through the

cell increases? If not, consider this question: does the electric cell have an electrical resistance?

The electrical resistance of a circuit element is defined as the ratio of the voltmeter reading across the element to the current flowing through it:

$$R = V/I,$$

where R is the resistance, V the voltage, and I the current. In the Daniell cell you have built, there is practically no resistance through the ammeter and wires that connect it to the cell. Hence, when the ammeter is connected to the electrodes, the voltmeter, which measures the product IR in the circuit outside the cell, will read close to zero. So where is the energy per charge that the voltmeter indicated was present before the ammeter was connected?

Leave a Daniell cell for several hours. Is there any movement of ions through the parchment barrier? How can you tell?

To see why a barrier is used in such a cell, try this. Place a small piece of zinc in a small amount of copper sulfate solution. What happens?

Next, use wire leads to connect two small zinc electrodes to a sensitive ammeter. Dip the electrodes first into zinc sulfate and then into copper sulfate solutions. If you observe any current in either solution, try jiggling first one electrode and then the other. What do you observe?

Repeat the process using two small copper electrodes. Then repeat again, but this time use one small copper and one small zinc electrode. Finally, try the experiment using zinc in a solution of zinc sulfate and copper in a solution of copper sulfate but in separate containers. Do you observe any current? Do you observe any current if you connect the two solutions with a piece of paper towel soaked in one of the solutions?

On the basis of your experiments and observations, why do you think a barrier is used in a Daniell cell?

***PROJECT 28:**
A better battery

To store the electricity generated from solar cells requires batteries that can be recharged thousands of times. If electric cars are to be a practical means of transportation, it will be necessary to develop a similar type of battery. Can you invent such a battery?

PROJECT 29:
Making an
electric motor

There are three basic parts to the motor; a stator, an armature, and brushes. Design and build a DC electric motor that will run on a 6-V battery. **Do not attempt to use electricity from an electric outlet** in your house.

PROJECT 30:
Magnetism
from electricity

Prior to 1819, most scientists thought that electricity and magnetism were unrelated, but in that year Hans Christian Oersted, a young Danish physicist, discovered, quite by accident, that a magnetic field surrounds an electric current.

To see this for yourself, place a magnetic compass above and touching a long, straight wire. The wire should be parallel to the compass needle. Carefully touch the ends of the wire to the poles of a battery made from two D-cells in series. (Don't let current flow for very long or the battery will wear out quickly.) What happens to the compass needle when charge flows along the wire? You have now seen what Oersted saw more than 150 years ago.

Now place the wire above the compass needle and let current flow through the wire again. Which way does the needle turn this time? What happens to the direction

of the magnetic field if you reverse the direction of the current by turning the battery around?

Try moving the compass needle farther from the wire. How far away from the wire can you detect a magnetic effect when current flows in the wire? If you use a stronger battery, using up to eight D-cells in series, can you detect any change in the strength of the magnetic field when a current flows? Can you offer a hypothesis to explain your observation? How can you test your hypothesis?

Design experiments to find the direction of the magnetic field around a current. (The direction of a magnetic field is given by the direction that a compass needle points in the field.) Iron filings may be useful to you. They behave like tiny compass needles in a magnetic field.

PROJECT 31:
Generating electricity

After Oersted's discovery, scientists began to look for the opposite effect: Could electricity be generated from a magnet? Michael Faraday was convinced that this should be so, but he was unable to generate any electricity by placing even very strong magnets near coils of wire. Then, on Christmas Day in 1831, he found the effect he had been looking for.

You can share his discovery by using long wires to connect a galvanometer to the ends of a coil of wire as shown in Figure 10. Watch the galvanometer needle as you move a strong bar magnet in and out of the coil. You have seen the same effect that Faraday found. Only when the magnetic field is changing do we find evidence of an electric current.

Today, with our understanding of the conservation of energy, Faraday's discovery makes sense. We would never expect to see electrical energy generated without some decrease in another form of energy, but Faraday did not know about the law of conservation of energy.

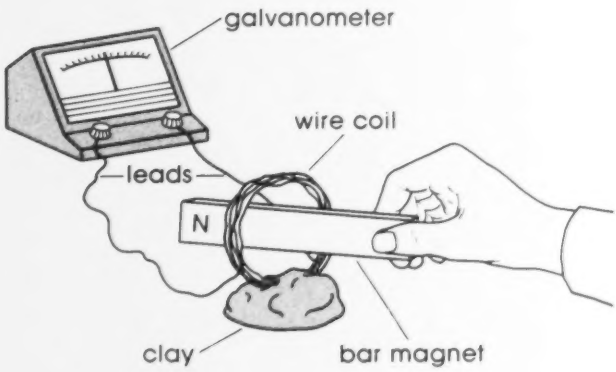


Figure 10 An electric generator

See if you can build a better electric generator, one that will light a flashlight bulb or turn a small electric motor. What forms of energy can you use to produce electrical energy from your generator?

5

ENERGY OF MOTION AND POSITION

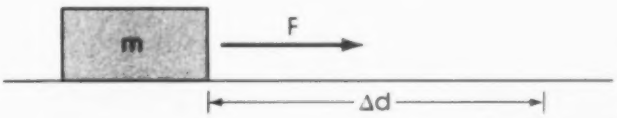
To scientists, work has a somewhat different meaning than it does to most people. Scientists define work as the product of a force and the distance through which that force acts in a direction parallel to the force.

WORK, KINETIC ENERGY, AND POTENTIAL ENERGY

If you pull a cart 10 m along a level floor with a net force of 100 N* in a direction parallel to the floor, the work you do on the cart is 1,000 N-m, or 1,000 J. As you do this work, you transfer energy to the cart. The motion that the cart acquires is called kinetic energy. You can see from Figure 11 that the kinetic energy the cart acquires ($\frac{1}{2}mv^2$) is equal to the work ($F\triangle d$) done on the cart.

You actually did more than 1,000 J of work in pulling the cart because there was friction between the wheels and the floor. The net force on the cart was 100 N, but you may have been applying a force of 105 N in order to overcome the 5 N of force between the wheels and floor.

*A newton (N) is the force you feel when you hold a 100-g mass in your hand.



Work done = $F \Delta d$

Since $F = ma$, work = $ma\Delta d$

But $a = \frac{v_f - v_i}{t}$, where v_f is the final velocity, v_i is the initial velocity, and t is the time during which v_i changed to v_f.

And $\Delta d = (\frac{v_f + v_i}{2})\, t$ since distance traveled = average velocity × time.

We conclude that:

Work = $F\Delta d = ma\Delta d = m(\frac{v_f - v_i}{t}) \times (\frac{v_f + v_i}{2})\, t$

$= \frac{m}{2}(v_f^2 - v_i^2) = \frac{1}{2} mv_f^2 - \frac{1}{2} mv_i^2$

The kinetic energy of a moving mass is defined as $\frac{1}{2} mv^2$. As you can see, the work done on the mass equals the change in its kinetic energy.

Figure 11 Work and kinetic energy

You did 1,050 J of work (105 N × 10 m), but only 1,000 J was transferred into the kinetic energy of the cart; the remaining 50 J has been transferred to thermal energy in the wheels and floor.

You do work whenever you lift a mass, because every object near the earth's surface is pulled toward the earth's center with a force of 9.8 N for every kilogram of mass in the object. This 9.8-N force per kilogram that the earth exerts on any mass, m, is called g. Hence, the weight of any mass, m, is m × g, or mg. Since any mass is pulled toward earth with a force of 9.8 N, you have to exert an equal force upward to prevent its fall.

If you lift a 1-kg mass to a height of 2 m, you do 19.6 J of work (9.8 N × 2 m). If that mass is then placed on a shelf, it can, if it falls, do 19.6 J of work by virtue of its position. By lifting the mass, you have stored energy in it. We call the energy stored in an object because of its position relative to the earth's surface gravitational potential energy.

In general, the gravitational potential energy (GPE) of an object is given by the product of its weight (mg) and its height (h):

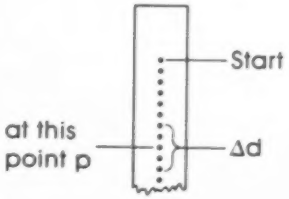
$$GPE = mgh$$

PROJECT 32:
The speed of a falling body

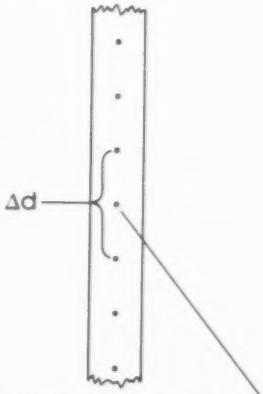
Simultaneously drop two balls that have different masses from the same height. You will see that both balls reach the floor at the same time. They accelerate at the same rate under the forces of gravity. In fact, you can prove to yourself that all masses undergo the same acceleration near the surface of the earth if air resistance is negligible.

What happens to the gravitational potential energy of a mass as it falls? What happens to its kinetic energy? Can you predict the speed of a mass after it has fallen various distances? To measure the speed, you can use a vibrating timer through which the falling mass pulls a narrow strip of white paper. A rotating piece of carbon

NIAGARA FALLS, IN UPSTATE NEW YORK. SUCH FALLING WATER IS A TREMENDOUS SOURCE OF ENERGY.



This $\frac{\Delta d}{\Delta t}$ gives the approximate instantaneous speed at point p, which might be 10 cm from the start. If $\Delta d = 4.0$ cm and we see that $\Delta t = 4 \times \frac{1}{60}\text{s} = \frac{1}{15}\text{s}$, then $v = \frac{\Delta d}{\Delta t} = \frac{4.0\text{ cm}}{\frac{1}{15}\text{s}} = 60$ cm/s.



At this point p′, much farther along the tape, say, 80 cm from start, v (at p′) = $\frac{\Delta d}{\Delta t}$. If $\Delta d = 6.0$ cm and $\Delta t = 2 \times \frac{1}{60}$ s, as you can see, then at p′,

$v = \frac{\Delta d}{\Delta t} = \frac{6.0\text{ cm}}{\frac{1}{30}\text{s}} = 180$ cm/s.

Figure 12 Measuring speed using "ticker tape"

paper beneath the timer's vibrator will leave a dot on the paper at equal intervals of time. (In many timers the time interval between vibrations is 1/60 s.) Or, with the help of an adult, you could use special spark paper tape that the falling mass pulls through a spark timer that generates an electric spark every 1/60 s. Other ways to measure speed would be to use electronic timers that you could place at different positions along the path of the falling mass, or a computer interfacing device.

Figure 12 shows how to measure speed at a particular place on a tape pulled through a vibrating or spark timer.

What happens to the speed of the mass as it falls? Were you able to predict its speed after it fell various distances?

Plot a graph of the speed of the mass versus the height through which it had fallen. Is its speed proportional to the distance it fell?

Try a graph of speed squared versus the height through which the mass fell. What do you find? How does the kinetic energy acquired by the falling mass compare with the gravitational potential energy lost during the fall?

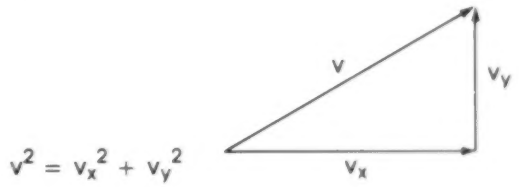
*PROJECT 33: The kinetic energy of a baseball

When you throw a baseball, you exert an average force on the ball through some distance. You therefore do work on the ball. The work that you do becomes the ball's kinetic energy. To determine the kinetic energy of the ball you will need to know both its horizontal velocity (v_x) and its vertical velocity (v_y) at the time you release it. Once these are known, the kinetic energy, K.E., can be determined because, as you can see in Figure 13,

$$\text{K.E.} = \tfrac{1}{2}\, mv^2 = \tfrac{1}{2}\, m\, (v_x^2 + v_y^2)$$

Once the ball is released, its horizontal velocity remains constant because the only force on the ball is gravity, which has no horizontal component.

THE BALL RELEASED BY A PITCHER'S ARM (IN THIS CASE THAT OF FORMER LOS ANGELES DODGER SANDY KOUFAX) HAS CONSIDERABLE KINETIC ENERGY.



$v^2 = v_x^2 + v_y^2$

Hence, $\frac{1}{2}mv^2 = \frac{1}{2}m(v_x^2 + v_y^2)$

Figure 13 Determining the velocity of a thrown baseball

Have someone use a stopwatch to determine the total time (t) the ball is in the air. By measuring the distance (x) it travels horizontally, you can calculate its horizontal velocity because $v_x = x/t$.

The ball's vertical velocity can be found from the fact that all objects near the earth's surface accelerate downward at 9.8 m/s^2; hence, the time for the ball to reach its peak height will be the time it takes for the ball's vertical velocity to change from v_y to zero. Since acceleration is the change in velocity ($\triangle v$) divided by the time,

$$\triangle v/t = g \text{ or } (v_y - 0)/t = g \text{ and } v_y = gt$$

The time for the ball to reach the peak of its path will be half its total time in the air; therefore, you can determine the ball's vertical velocity by multiplying half the ball's time in the air by g.

What was the kinetic energy of the ball you threw? How much work did you do on the ball? If you can find a way to measure the distance your arm moves as you throw a ball, you can determine the average force that you exert on the ball. How does it compare with the average force that others exert?

Knowing the mass and velocity of the ball, you can

easily find the ball's momentum at its point of release. Since the momentum the ball acquires is the product of the average force and the time that force was exerted, you can also determine the time that it took you to throw the ball.

What simplifying assumptions have been made in this experiment?

***PROJECT 34:**
Kinetic energy of a batted ball

Design and conduct an experiment to determine the kinetic energy of a batted ball or one hit with a fungo bat.

PROJECT 35:
Elastic potential energy

Choose a spring that increases in length by about 0.3 to 0.5 m when a 1-kg mass is hung on it. To such a suspended spring, attach a kilogram mass and support it so the spring is not stretched. Then release the mass so it falls stretching the spring as it goes. Mark the points of zero and maximum stretch as shown in Figure 14. Notice that the contracting spring returns the mass to very nearly the point from which it was released. This shows that the gravitational potential energy that the mass lost is stored in the stretched spring in a form of energy called elastic potential energy.

To find a relationship between the elastic potential energy and the stretch of the spring, measure the maximum stretch of the spring when various masses (1.0, 0.7, 0.5, and 0.2 kg) are released while attached to the unstretched spring. From the gravitational potential energy lost by the mass, you can determine the elastic potential energy acquired in each case since they are virtually the same.

Plot a graph of the elastic potential energy stored in the spring for each mass that fell versus the stretch of the spring. Is the elastic potential energy in the spring propor-

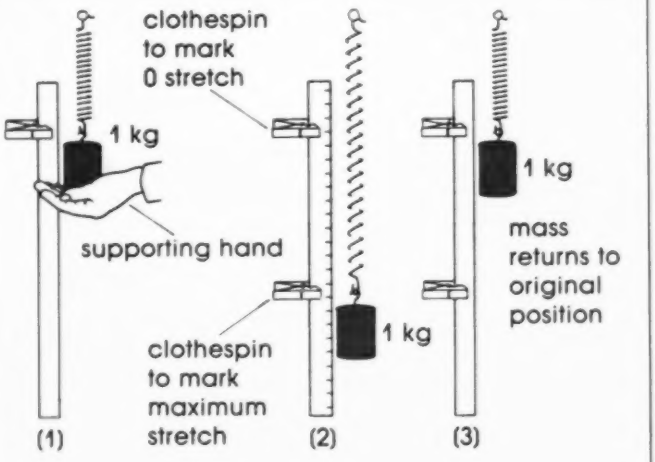


Figure 14 A falling mass stretches a spring

tional to the spring's stretch? If not, plot elastic potential energy versus the square of the spring's stretch. What does this graph tell you? Write the equation for the graph.

PROJECT 36:
Another look at elastic potential energy

To check up on the relationship you have just found, you can measure the stretch (increased length of the spring), in meters, versus the force on the spring. Mark the bottom of the spring when it is not stretched at all. Then attach a 0.20-kg mass to the spring and carefully lower the mass until the spring stops stretching. Measure the increased length of the spring when this force of 1.96 N pulls on the string. Repeat using forces of 4.9, 9.8, and 14.7 N by

hanging masses of 0.50, 1.00, and 1.50 kg from the spring. Record the increased length of the spring for each force.

Now plot a graph of the force applied to the spring versus the stretch of the spring. Is the stretch proportional to the force applied?

Notice that the area under the graph of force as a function of stretch measures the work done on the spring or the potential energy stored in it. Write the equation for the graph you have just drawn. How do the results of this experiment compare with those in Project 35?

*PROJECT 37: Between gravitational and elastic potential energy

The gravitational potential energy lost when a mass falls while attached to a spring has changed to elastic potential energy when the mass stops falling. The elastic potential energy is then changed back to gravitational potential energy as the mass ascends to its original position. But during the transition from one form of potential energy to another, there exists not only gravitational and elastic potential energies but kinetic energy as well.

Recognizing that energy is conserved, try to predict how much kinetic energy should exist at various points in the oscillation of a mass on a spring. Then determine by an experiment of your own design whether your predictions are correct.

PROJECT 38: Building better bumpers

When molecules of gas collide, the collisions are generally elastic; that is, the total kinetic energy of the molecules before and after the collisions is the same. However, collisions of most common objects are inelastic because some kinetic energy is lost during the collision.

In an elastic collision, some kinetic energy is converted to potential (often elastic potential) energy as

the colliding bodies approach, but the potential energy is returned to kinetic as the bodies separate. Inelastic collisions, such as the collisions of cars, are evident by the permanent change in structure. The metals dented or bent in the collision are not sufficiently elastic to return to their original shape; consequently, the work done in compressing materials as the objects approach one another is never returned. The result is crumpled, permanently damaged matter.

From what you have learned about elastic potential energy and collisions, see if you can design a better bumper for automobiles, one that will resist permanent deformation and make collisions more elastic. As you work on your design, think about the occupants of such cars. Will your design provide greater safety to the passengers?

PROJECT 39:
Potential energy in molecules

When you boil a liquid, the temperature of the liquid does not change despite the fact that thermal energy is being added to the liquid. However, the liquid does disappear as it changes to a gas. Careful measurements show that the temperature of the gas is the same as that of the boiling liquid. Could it be that the separation of the molecules as they change from liquid to gas results in potential energy among the molecules, just as the separation of a mass from the earth leads to an increase in gravitational potential energy?

To test this idea, see what happens when a gas condenses to form a liquid. If potential energy increases when molecules separate, then we might expect a decrease in potential energy when the gas molecules coalesce. This decrease in potential energy should result in the release of an equal amount of another form of energy—probably the kinetic energy of molecules, which we call thermal energy.

Use a steam generator and trap as shown in Figure 15 to produce steam. (**Be careful. Steam can burn you.**)

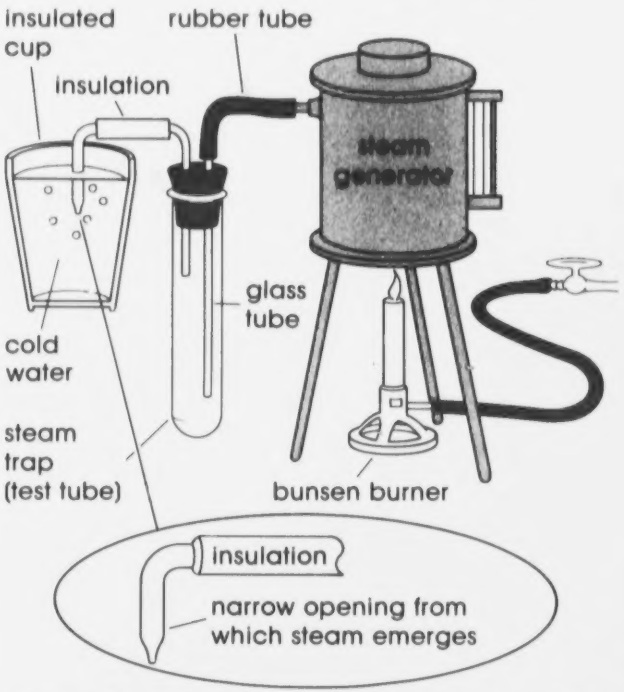


Figure 15 Measuring the heat of condensation

You can then condense some of the steam in cold water and see how much heat is transferred per gram of steam condensed.

Cut an insulated coffee cup in half and determine its mass. Fill the cup about three-fourths full with cold water about 10°C below room temperature and reweigh. Determine the temperature of the water. Then place the tapered glass tube from which steam is emerging into the cold water.

Allow steam to condense in the water until its temperature rises about 10°C above room temperature.

Remove the water from the steam source and record its final temperature. Then reweigh to find out how much steam condensed. Why should you let the temperature of the cold water rise until it is about as many degrees above room temperature as it was below room temperature when the experiment started?

The temperature rise of the cold water will tell you how much heat was transferred; however, not all that heat came from the condensing steam. Remember, after the steam has condensed, it is at the temperature of the boiling water (about 100°C). The condensed steam in cooling to the final temperature of the water loses heat. By subtracting this heat from the total heat transferred to the cold water, you will be left with the heat that came from the condensation of the steam.

How much heat was released per gram of steam that condensed?

Is there evidence to support the idea that potential energy is stored in molecules when they separate?

***PROJECT 40:**
Heat of vaporization

It is more difficult to measure the heat of vaporization (the heat required to change a gram of liquid to vapor at the boiling point) than the heat of condensation, because it is not easy to compensate for the large heat losses to the surroundings that occur at 100°C.

To obtain an approximate value, first calibrate an immersion heater. Place about 150 g (150 ml) of cold water in a 12-oz styrofoam cup. The large size of the cup will reduce water losses due to spattering when the water boils and the insulation will reduce heat losses. Measure the temperature change of the water when the immersion heater is used to heat the water for a period of 1 min. **Never connect an immersion heater to an electrical outlet unless the heater is in water.**

How much heat does the heater deliver in 1 min?

Use the same heater to bring 150 g of water to boiling. Let the water boil for several minutes so that some of

the water is converted to gas (steam). At a convenient time, disconnect the heater, and carefully pour the water that remains into a graduated cylinder. How much liquid water was changed to gas? How much heat was added to the water? How much heat was required to boil away 1 g of water? (Remember to subtract the heat that was required to bring the water from its initial temperature to the boiling point.)

How does your value for the heat required to boil away a gram of water compare with the heat released when a gram of steam condenses? How would you expect these values to compare?

Design an experiment to reduce or compensate for heat losses and thus obtain a better value for the heat of vaporization of water.

PROJECT 41:
The heat of melting

The heat required to melt 1 g of solid at its melting temperature is called the heat of melting. Design and carry out an experiment to determine the heat of melting for ice.

The heat of fusion is the heat that must be removed from 1 g of a substance to change it from liquid to solid at the freezing temperature. How would you expect the heat of fusion and the heat of melting of the same substance to compare? Design an experiment to measure the heat of fusion for water.

***PROJECT 42:**
The heat of fusion for hypo

See if you can determine the heat of fusion for sodium thiosulfate ($Na_2S_2O_3 \cdot 5H_2O$), known to photographers as hypo. Place a test tube half full of the crystals in a beaker of hot water to make them melt. This substance freezes at 48°C, but it is easily supercooled to 35°C or lower. So it is best to cool it to about 35°C and then add a tiny crystal

of the substance, called a seed crystal, to initiate the freezing process.

After it freezes, let it cool back to 35°C before making any final measurements. Any heat required to raise the hypo from its supercooled temperature to its freezing temperature will be returned when it cools back after freezing. Cool water in an insulated cup can be placed around the test tube of hypo to measure the heat of fusion once the hypo starts to freeze

Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) is a substance that has been used to store solar energy, so you might like to measure its heat of fusion for future use if you do solar energy projects.

6

SOLAR ENERGY

The source of the chemical energy stored in fossil fuels, which are the major source of humankind's energy today, the source of the energy that drives windmills, the source of the energy that lifts water into the atmosphere from which it can fall and flow over dams providing the kinetic energy to turn the turbines that generate electricity—the source of all these energies is solar energy, the energy that comes to us from the sun. It is the earth's only outside source of energy, and it is free.

Solar energy has none of the pollution associated with the burning of coal and oil, and we do not have to tear the earth open to find it. Sunlight falls on every nation of the world, and cannot be controlled or hoarded by select nations or terrorists.

Unfortunately, solar energy is diffuse—there is relatively little energy per unit area. Consequently, to use solar energy efficiently we must build devices that concentrate the light onto smaller areas, or collecting devices that have large surface areas.

PROJECT 43:
Heating air with solar energy

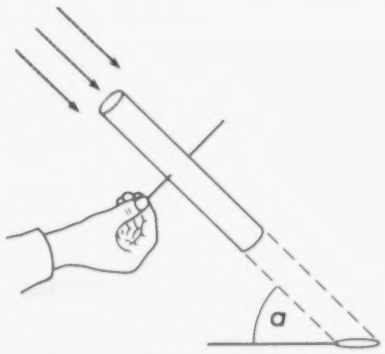
To see how solar energy can be used to heat air, first find two identical aluminum pie pans. Paint the inside of one

with flat black paint. When the paint has dried, fix a thermometer to the edge of each pan with masking tape. Be sure the tape covers the thermometers' bulbs so that sunlight does not fall directly on the glass bulbs. Place each pan and thermometer inside identical clear plastic bags. Seal the bags with tie bands. Place both pans in a box and position the box so that sunlight is perpendicular to the surface of the pans.

Check the air temperatures in the bags periodically until the temperatures stop rising. Which pan converts more solar energy to heat?

Repeat the experiment using a large and a small pan both painted black. Which pan produces more heat?

This time use several black pans. Vary the angle that each pan makes with the sun's rays. To find a surface that is perpendicular to the sun, mount a soda straw on a pin and hold it above a flat surface as shown in Figure 16. When the straw casts no shadow of its sides, you know it is



Hold straw so it is parallel to sun's rays. Then it casts no shadow (other than a ring). Measure angle *a* to obtain sun's altitude.

Figure 16 Measuring the sun's altitude

parallel to the sunlight. Use a protractor to measure the angle that the sun's rays make with the ground. How can you determine the angle between the sun's rays and the surface of each pie pan tilted at different angles?

Which angle seems to produce the maximum amount of heat from solar energy?

PROJECT 44:
Heating water with solar energy

Water, too, can be warmed by the sun's energy. To see how this is done, place 100 ml of water in each of two aluminum pans. One of the pans should be painted black as in Project 43; the other should not be painted. Place both pans on an insulating sheet of cardboard in a warm, sunny location. How can you determine which pan will convert more solar energy to heat?

Repeat the experiment, but this time use two unpainted pie pans. Add enough black ink to one pan to make the water very dark. Which pan do you think will produce more heat from sunlight?

PROJECT 45:
Color and solar energy

Does the color of a house or roof have any effect on the solar energy reflected or absorbed? To find out, cover the bulbs of several thermometers with small sheets (5 cm × 10 cm) of colored construction paper. You might choose red, green, blue, white, black, and any other colors that you may want. Fold the paper around each thermometer bulb in the same way. Use a paper clip to hold the paper in place.

Note the temperature within each colored paper before placing the thermometers side by side on an insulating sheet of cardboard in a bright, sunny place. Record the temperature within each colored sheet at 1-min intervals for a period of about 15 min.

Which color seems to be best suited for converting

light to heat? Which one seems to be the best reflector of light?

In the winter, you might do this experiment by placing pieces of metal, identical in every way except for their color, on the surface of some snow. How can you determine which piece of metal is converting the most sunlight into heat?

PROJECT 46:
The greenhouse effect

The place where you have most likely seen the greenhouse effect, strangely enough, is not in a greenhouse but in a car. If you have ever stepped into a car that has been tightly closed and sitting in the sun for some time, you have undoubtedly noticed how much warmer it is inside the car than outside. This warming of a glass-enclosed structure sitting in sunlight is called the greenhouse effect. In a similar manner, the earth's atmosphere reflects radiation back to the ground creating a greenhouse effect on a global scale.

To get a closer look at this effect, place a small thermometer inside a glass jar. Insert a piece of cardboard as shown in Figure 17 to be sure that the thermometer bulb is

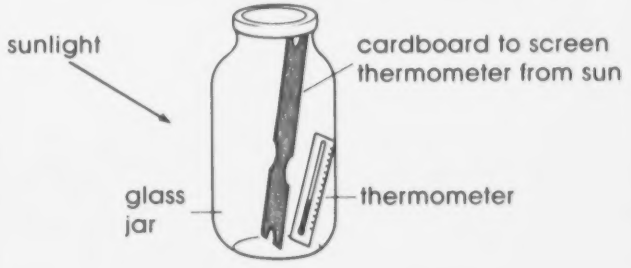


Figure 17 A small greenhouse

shaded. Place the jar in bright sunlight with its sun-facing side perpendicular to the sunlight. Watch the temperature in the jar for a few minutes. What happens?

Can you get the temperature to rise higher by covering the top, bottom, and back side of the jar with insulation?

Does the angle that the sun-facing side of the jar makes with the sunlight have any effect on the rate at which heat is produced in the jar?

From what you have learned, see if you can design and build a model greenhouse that will collect solar energy. If you are successful, perhaps you can design and build a greenhouse on the south side of your house that will serve as an additional heat source and reduce your family's heating costs. At the same time, you will have a warm room for winter living as well as a place to grow plants year round.

PROJECT 47:
A model flat plate collector

You have probably seen solar collectors on the south-facing roofs of a number of homes or commercial buildings. These collectors are usually used to heat water. If, as is usually the case, pumps are used to move water between the collectors and the tank where the hot water is stored, the collectors are referred to as active solar collectors. Generally, there is a backup system to ensure the presence of hot water if the weather is cloudy for several days. Occasionally, active solar collectors are used to heat air in buildings as well, but more commonly passive methods—methods that do not involve the use of electrical devices such as pumps—are used to heat the space within buildings.

You can build a small model solar collector in the following way. First, cut the flaps from a cardboard box (about 20 cm × 30 cm × 10 cm deep). Fill the lower half of the box with crumpled newspaper for insulation. Punch a hole in one corner of the box about 3.8 cm from the top and one side as shown in Figure 18. Push the spout of a

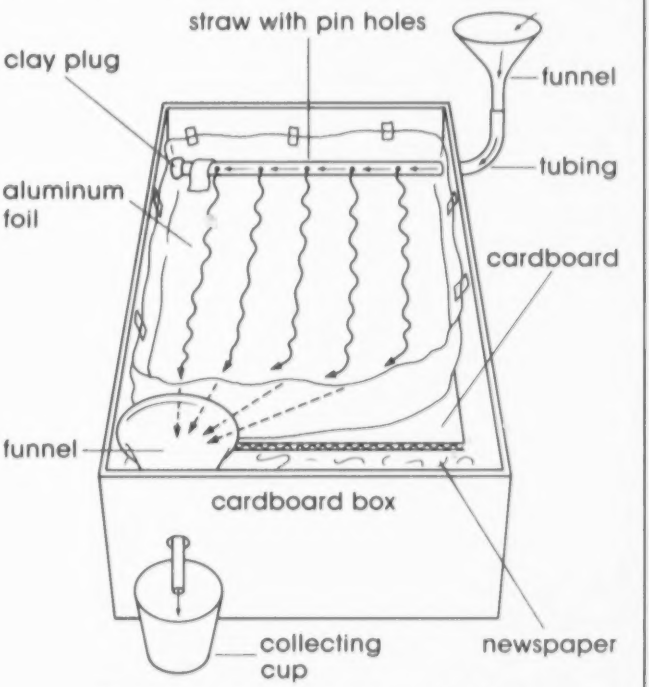


Figure 18 A model solar collector

funnel through the hole. The funnel rests in one corner of the box and serves to collect water that will flow down the surface of the collector.

Next, cut a sheet of cardboard the same width as the box. Its length should equal the distance from the top of the funnel to the other end of the box. The fit should be a snug one to help hold the funnel in place. Cut a piece of heavy-duty aluminum foil about 5 cm wider than the box with a length equal to that of the box. Paint the aluminum with flat black paint.

SOLAR-HEATED COAST GUARD STATION IN PROVINCETOWN, MASSACHUSETTS.

Once the paint is dry, lay the foil on the cardboard. Fold the "extra" foil against the sides of the box and tape it firmly in place. Turn up the bottom edge of the foil to form a trough that will carry water into the funnel. Punch a hole through the foil above the funnel so that water can run out of the box into a collecting cup.

Use a thick pin to punch six to seven holes in a straight line along one side of a giant (0.8 cm in diameter) plastic soda straw or tube. Punch a hole in the upper corner of the box and push the straw through the hole. The straw should rest on the aluminum foil with its holes near the foil's surface. A clay plug over the end of the straw within the box will force water to flow out the holes. Use tape to

fasten the straw firmly against the aluminum foil. The other end of the straw protrudes through the box and is connected to another funnel by a short piece of rubber tubing.

Place the box in a sunny place with the aluminum foil facing the sun. After measuring the temperature of 50 ml of cold water, pour the water into the upper funnel. The water will flow into the straw, out the small holes, and down the warm aluminum foil to the trough, where it will collect and run into the funnel and out of the collector into a cup.

In a real collector a pump would return the water to the top of the panel after it had passed over the warm metal surface and into a storage tank. In this model collector you will have to remove the cup and pour the water back into the upper funnel so that the water may again flow over the metal foil. Be sure to put another cup under the lower funnel.

After the water has flowed over the collector surface a number of times, measure the water temperature again. How much has the temperature risen? How much warmer can you get the water by repeating the process again?

Cover the open side of the box with plastic wrap and tape the clear material to the sides of the box. Repeat the experiment. Why does the water heat up faster this time?

Now see if you can build a better model solar collector. As you become more and more familiar with these devices, you may want to build a collector that can actually be used to heat water in your house. Will you use water or air to transfer heat?

PROJECT 48:
Which way is south?

To build a solar home, one that will use sunlight passing through windows to at least partially heat the building, the architect and builder must know which direction is

south so that large windows will face the winter sun.

The simplest method is to find the North Star and align it with several sticks to get a north-south line. But this may be difficult to do on a moonless night.

You can obtain a north-south line in another way during the midday hours. At about 11 AM, standard time, on a sunny day, push a stick into the ground. Be sure the stick is vertical. With a string and a sharp stick scratch a circle around the vertical stick using the shadow of the stick as a radius. Mark the spot where the shadow touches the circle with a stone. The shadow will continue to move and grow shorter as midday approaches. After midday (this does not necessarily occur at 12 o'clock noon), the shadow will grow longer and continue to move eastward. Finally, it will touch the circle again. Mark this point with another stone.

Next, draw a chord of the circle by drawing a straight line between the two stones. A line from the stick to the midpoint of the chord will be a north-south line. Explain why this method works, and also explain why a magnetic compass is not a satisfactory way of finding true north in most places.

Some architects maintain that the solar-collecting windows of a solar house should actually face a little west of south. Do you agree with this?

PROJECT 49:
Mapping the sun

A solar house must have south-facing windows to collect energy from the winter sun. Unfortunately, these windows will allow light from the summer sun to pass through them as well, and the sun stays above the horizon much longer each day in the summer than in winter.

By knowing the position of the sun at various times of the year, an architect can design the roof overhang so as to enhance winter heating by the sun while shading the window when the summer sun is higher in the sky.

When you stand in an open space and look upward, you see a hemispherically shaped sky surrounding you. At night, stars glisten like tiny lights set in this huge hemi-

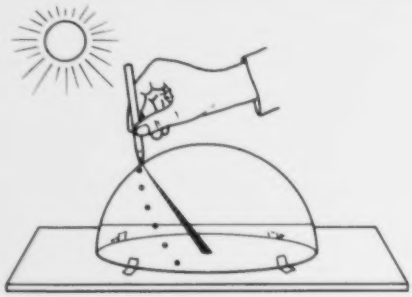


Figure 19 Mapping the sun

sphere. You are at the very center of what astronomers call the celestial hemisphere.

To map the sun's path across the sky you'll need a clear plastic dome or a fine mesh kitchen strainer to represent the hemispherical sky (celestial hemisphere). Put the dome or strainer on a sheet of heavy cardboard. Mark the outline of its base with a pencil. Then remove the dome or strainer and make an X at the center of the circle you have drawn. The X represents your position at the center of the celestial hemisphere. Put the strainer back in its original position and tape it to the cardboard.

Place the dome outside on a level surface shortly after sunrise. To map the sun's path, place the tip of a marking pen on the dome so the shadow of the tip falls on the X at the center of the circle as shown in Figure 19. Mark this point on the dome with your pen. The pen mark on the dome represents the position of the sun in the sky because it is directly in line with the real sun and the X that represents you.

Make marks like this at half-hour intervals throughout the day. By sunset you will have a map of the sun's path across the sky.

If you mark north and south on this dome, you can use

the same dome to map the sun at different times of the year.

If you use a strainer, colored round-headed pins can be used to cast shadows on the X. Leave the pins in the strainer; they will provide a colorful map of the sun's path. To make a permanent record of the sun's path, run a piece of colored yarn through the pins' positions as you remove them.

Repeat this experiment at different times of the year. Try especially hard to map the sun on or about the 20th of September, December, March, and June. These dates give particularly interesting maps because they mark the beginning of the seasons. The maps for June and December will give you the sun's maximum and minimum midday altitudes respectively.

When does the sun rise in the direction due east and set in the direction due west?

How can you use these maps of the sun's path across the sky to determine the altitude of the sun in summer and winter? How will this help you design the proper overhang for a roof on a solar-heated home?

PROJECT 50:
Storing solar energy

A house with plenty of south-facing windows may become so warm on a bright January day that a window will have to be opened; yet, after sunset, an alternative heating system will have to be turned on to replace heat lost to the cooler surroundings. To prevent such wide fluctuations in temperature, there are ways to "bottle" excess daytime solar energy and store it for use at night when outside temperatures plummet.

The Pueblo Indians used thick adobe walls to "soak up" solar energy. Today, many solar home builders use Trombe walls—massive, dark concrete walls in front of south windows—to absorb heat. Air between the wall and window is heated, rises and passes through slots into the room as cooler air enters through ducts at the base of the wall. During the day the wall absorbs heat which is

INSIDE THE BROOKHAVEN HOUSE. THE SOUTH SIDE OF THE HOUSE FEATURES SPECIAL WALLS AND GLASS AND CONTAINS THE MAIN LIVING AREAS, WHILE THE NORTH SIDE FEATURES BUFFERING SPACES AND A WELL-INSULATED BUILDING SHELL. HEAT FROM SUNLIGHT IS TRAPPED BY THE GLASS AND ABSORBED BY THE THERMAL WALL, FROM WHERE IT RADIATES INTO THE ROOMS.

then available to warm the building at night. To reduce heat losses, the windows are covered with insulating material after sunset.

To find suitable materials to use for storing solar energy you can place small identical cans filled with various substances such as gravel, stones, sand, dirt, salt, and water in a 50°C (120°F) oven until all the substances are at that temperature. (Be sure to cover the water so it can't evaporate.)

Using potholders so you won't burn your fingers, remove the substances from the oven, and record their temperatures as they cool. Which substance cools fastest? Slowest? Which one would you recommend for storing solar energy?

To test your recommendation, paint the cans with flat black paint. After the paint is dry and the substances are all at the same temperature, place the cans in a sunny place where all can receive the same amount of sunlight throughout the day. Toward the end of the day, measure the temperature in each can. Which substance has gained the most heat? (You'll need a balance to weigh the materials and an extra empty can. A table of specific heats can be found in Appendix 2.)

Now leave the cans in a room until they all reach room temperature. Which can lost its heat fastest? Which one cooled slowest?

Would you still recommend the same substance to store solar energy?

*PROJECT 51: Storing solar energy in salt or water

If you measured the heat of melting of Glauber's salt ($Na_2SO_4 \cdot 10H_2O$) in Chapter 5, you know that energy can be stored in the melted salt as chemical potential energy, or *latent heat*. If solar energy were used to melt the salt, that energy, which would be released when the salt freezes, could be used later as a heat source when solar energy is no longer available. A number of people, including Maria Telkes (see Selected Reading), have experimented with Glauber's salt as well as other salts with low melting points such as sodium thiosulfate pentahydrate ($Na_2S_2O_3 \cdot 5H_2O$). They claim that these salts can be used to heat buildings in the winter and keep them cool in the summer.

Others have experimented with roof ponds—shallow tanks of water that rest on a flat roof. These ponds absorb solar energy during the daytime. At night they are

covered and insulated so that the energy stored in the water can radiate heat into the living space below. During the summer, these same ponds can be used to absorb solar energy so that it does not reach the living space. Then at night, the pond, if left exposed to the dark sky, will radiate the energy absorbed during the daytime.

See if you can design a model system that uses a roof pond or one or more salts with low melting points to store solar energy. If you are successful and want to be rich and famous, you might like to build a system that could be used to store solar heat in buildings.

***PROJECT 52:**
Tracking the sun

You've found that the maximum rate of solar energy absorption occurs when the collecting surface is perpendicular to the sun's rays. Therefore, it would be advantageous to have solar collectors turn with the sun and even vary their elevation if possible. To date, this has been too expensive in terms of the payback; consequently, most solar collectors are built to face south and are tilted at an angle that makes them reasonably close to being perpendicular to the winter sun's midday light.

See if you can design and build a model for a device that will keep a solar collector facing the sun. If you succeed, you might want to try to build a commercially feasible device. You will probably be able to find financial support from a solar energy company for such a project if your model appears to be practical both mechanically and economically.

PROJECT 53:
Building a model solar home

Solar homes not only must collect and store solar energy, but also must trap that heat within their walls so that it doesn't easily escape. Consequently, these buildings must be well insulated and weather stripped. With the

THE BROOKHAVEN HOUSE. THE GLASS-ENCLOSED AREAS WARM UP FROM SUNLIGHT AND TRANSFER THE HEAT INTO THE HOUSE. WHAT DO THESE GLASS STRUCTURES REMIND YOU OF?

exception of the south side, there should be few windows, and those should be double or triple glazed and covered at night with insulating shutters or shades.

Now that you've learned something about collecting, storing, and trapping solar energy, you might like to try your hand at building a model solar buildling that uses passive solar energy as a heating source. If your model is a successful one, you might like to apply what you have learned to the design and eventual construction of your own passive solar home.

***PROJECT 54:**
A window box heater

If you're not ready to design a solar home, you might like to tackle a less ambitious, but useful, project. Design and build a solar heater that would help warm at least one room in your home. Such a heater could be built just outside a south-facing window.

PROJECT 55:
Storm windows and doors

Most well-built homes, whether solar or not, have storm windows and doors to reduce heat losses through glass and uninsulated wood.

To see the effect of storm windows and doors, find a small, thick cardboard box just about big enough to hold a glass of water. With a sharp knife cut a window on four sides of the box as shown in Figure 20. Fill the glass about three-fourths full of room-temperature water and place it in the box. Tape the top of the box and other seams. Punch a hole through the top so a thermometer can be pushed through the box and into the water.

Place the box in a refrigerator and record the temperature at 5-min intervals as the box cools through at least 10°C (18°F).

Repeat the experiment, but this time tape a layer of plastic wrap over the window on the *inside* of the box. Pull the wrap so that it is taut and tape it firmly to the

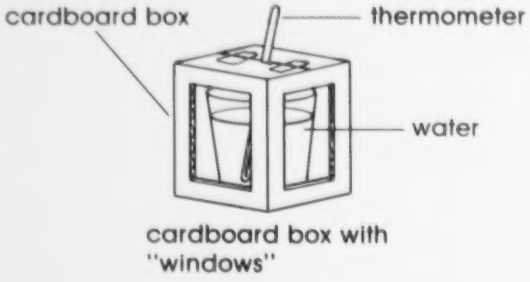


Figure 20 Testing storm windows

inside surface of the box. How does the rate at which heat is lost from the water this time compare with the first run?

Now tape a taut layer of the plastic wrap to the outside of the box. Be sure the two layers do not touch so that there is a layer of air between them. Again repeat the experiment. What do you find about the rate at which heat is lost this time? How do you explain your results?

What could you do to further reduce the rate at which heat is lost from the box?

PROJECT 56:
Solar energy to mechanical energy

When stretched, polymer plastic strips, which can be made by cutting up polyethylene garbage bags, will contract upon heating. You could of course heat them with sunlight. With patience and ingenuity, you might be able to construct a solar-powered motor that could be driven by the conversion of light energy to chemical energy to kinetic energy.

If you enjoy tinkering, give this a try. It may not lead to a very efficient engine, but it should be fun.

***PROJECT 57:**
The solar constant

The energy that we receive from the sun varies from day to day depending on the season, the amount of cloud cover, air pollution, and other factors. But just above our atmosphere the radiant energy from the sun is very nearly constant. Since the energy from the sun is so vast, we usually measure not the total energy but the power per area. We call this value the solar constant. It is 1.95 cal/cm^2/min, or 1,353 W/m^2.

Design an experiment to measure how much solar power reaches your part of the earth at any given time.

7

SAVING ENERGY AT HOME AND SCHOOL

By reducing our use of energy, we extend the lifetime of conventional energy sources such as fossil fuels, improve the quality of the air we breathe, and reduce this nation's dependence on foreign energy sources as well as our energy bills.

In this chapter you'll have an opportunity to try some energy-saving projects and to discover some methods that could help your family and school reduce their use of energy and, therefore, the money they spend on energy.

PROJECT 58: Electrical appliances and energy conservation

There are many electrical appliances in your home and school. To find the energy needed to operate an appliance for one year you need to know two things: its power rating in watts and the number of hours the appliance is used.

Usually, you can find the wattage rating printed on the appliance or in the manual that came with the appliance. In some cases you may find a plate that gives

the current and voltage at which the appliance operates. Given this information, how could you find the power?

Next you will have to make reasonable estimates of the time that each appliance is used during a year. From your estimates of time and the power ratings, how can you determine the energy, in kilowatt-hours, that each appliance requires per year?

Make a survey of all the appliances in your home or school. How much energy is required to operate each one? Based on the cost of electricity, which you can find on a recent bill from your power company, how much does it cost to operate each appliance for one year? How do your values compare with those in Table 5, which gives the average values for wattage and hours used for various appliances? The last column gives the operating cost per year based on a figure of 5 cents per kilowatt-hour.

TABLE 5
The power and energy use of various appliances

Appliance	*Average wattage*	*Average number of hours used per year*	*Kilowatt-hours per year*	*Cost to run per year ($)*
Kitchen				
Blender	390	40	15.6	0.78
Broiler	1,400	70	98	4.90
Coffee maker	900	120	108	5.40
Dishwasher	1,200	300	360	18.00
Range	12,200	100	1,220	61.00
Microwave	1,450	130	189	9.45
Toaster	1,200	35	42	2.10
Waffle iron	1,100	20	22	1.10
Refrigerator (12 cu ft)	240	3,000	720	36.00

TABLE 5 (continued)

Appliance	*Average wattage*	*Average number of hours used per year*	*Kilowatt-hours per year*	*Cost to run per year ($)*
Frostless refrigerator (12 cu ft)	320	3,800	1,220	60.80
Freezer (15 cu ft)	340	3,500	1,190	59.50
Frostless freezer (15 cu ft)	440	4,000	1,760	88.00
Laundry				
Clothes dryer	4,800	200	960	48.00
Iron	1,000	140	140	7.00
Washing machine	500	200	100	5.00
Water heater	2,500	1,600	4,000	200.00
Quick-recovery water heater	4,500	1,000	4,500	225.00
Comfort				
Air conditioner	900	1,000	900	45.00
Electric blanket	180	830	149	7.45
Dehumidifier	250	1,500	375	18.75
Fan (attic)	370	800	296	14.80
Fan (window)	200	850	170	8.50
Humidifier	180	900	162	8.10
Health and Beauty				
Hair Dryer	750	50	37.5	1.90
Shaver	14	80	1.12	0.06
Sun lamp	280	60	16.8	0.84
Toothbrush	7	60	0.42	0.02
Entertainment				
Radio	70	1,200	84	4.20
TV (B/W, tube)	160	2,200	350	17.60

TABLE 5 (continued)

Appliance	*Average wattage*	*Average number of hours used per year*	*Kilowatt-hours per year*	*Cost to run per year ($)*
TV (B/W, solid-state)	55	2,200	121	6.05
TV (color, tube)	300	2,200	660	33.00
TV (color, solid-state)	200	2,200	440	27.00
Housewares				
Clock	2	8,760	17.5	0.88
Vacuum cleaner	630	75	47	2.36
Sewing machine	75	140	10.5	5.25
Lighting				
Light bulbs (on, in home)	660	1,500	1,000	50.00

Suggest ways to help your family or classmates and teachers reduce the use of these appliances. For example, turn off lights when they are not needed, use a clothesline instead of a dryer when the weather is clear, use a dishwasher only when it is full of dishes, turn off the water heater when your family or school goes on vacation, etc. How much money will be saved if they follow all your suggestions?

If your family or school decides to follow your suggestions, you can check the electrical energy used *after* your suggestions were put into effect with the energy used *before*. How can you determine how much money has been saved because of your project? Why is a comparison of this year's energy bill with last year's a poor way to estimate savings? What figures should be compared?

PROJECT 59:
Saving heat

One way to reduce energy use in the winter is to turn back the thermostat(s) in your home or school to 18°C (65°F) during the daytime and 10°C (50°F) at night or when people are not in the building. (If you have electric heat, this could be included as part of Project 58.)

To see what impact this has on your heating bill, determine the amount of gas, oil, or electricity that you used last year for heating with the amount used after you instituted a thermostat set-back program. Then divide total fuel used for each winter by the number of degree-days in that winter.

If you use gas or electricity for heat and other jobs that require energy, compare winter electric or gas bills with summer bills. The difference is probably due to heating.

Calculate the money saved because of thermostat set-back.

PROJECT 60:
Be a house doctor

Doctors give their patients physical examinations. Armed with the knowledge you gleaned from the projects in this chapter and Chapter 3, you can be a house doctor, one who examines not people but houses. A house doctor carries a checklist, a thermometer, a draftometer,* a measuring tape, a pocket calculator, and some handy charts. After giving a house a thorough examination, the "doctor" may suggest to a homeowner ways to reduce energy use. Suggestions may involve reducing conductive heat losses, infiltration, and/or various conservation measures.

As a house doctor you might begin your examination by using a series of energy checklists to be sure you

*A draftometer is a narrow strip of plastic wrap. It will move in air currents and can be used to detect infiltration.

AN ENERGY AUDIT MAY TURN UP HOLES LIKE THIS
THROUGH WHICH HEAT CAN ESCAPE AND COLD AIR ENTER.

check all the ways that energy may be wasted in the house you are examining. You might give a copy of your checklists to the owner. The owner will view these as suggestions that can be implemented if he or she chooses to do so. After your examination, point out to the owner any serious energy wasters that you have discovered.

Here are some checklists to use. You may want to add to, or delete from, these suggested checklists as you see fit.

AROUND-THE-HOUSE CHECKLIST

- Dishwasher—is the dishwasher used only when filled? After the rinse cycle, are the dishes allowed to air-dry rather than using the electric heater in the washer? Is cold water or a pan of warm water used to rinse dishes rather than a stream of hot water?
- Is the refrigerator set at 40°F? (A colder temperature is not needed.)
- Are the gaskets around the refrigerator and freezer doors tight enough to hold a dollar bill firmly?
- Is the freezer at 32°F? Is it full? (It's uneconomical to operate an empty or half-filled freezer.)
- Are clothes washers and dryers operated only for full loads?
- Are clothes washed in cold or warm water when possible? Are they rinsed in cold water?
- Are soiled clothes soaked before washing?
- When large quantities of clothes need to be dried, they should be dried in consecutive loads so that the dryer's mass has to be heated only once.
- Is the lint screen cleaned after each load is dried?
- Is the outside vent cleaned frequently?
- Are clothes dried on a clothesline in clear weather?

- Are hot-water pipes insulated to reduce heat losses?
- Are hot-water tanks wrapped in insulating blankets? There are kits available for this.
- Is the water heater turned off when occupants are away for long periods?
- Is the thermostat setting on the water heater set higher than it need be?
- Do the occupants take quick showers rather than baths to reduce hot-water use?
- Are lights and other electrical appliances turned off when they are not in use?
- Are light bulbs and fixtures clean?
- Are outside lights turned off when they are not needed?
- Has fluorescent lighting been substituted for the more costly incandescent lighting wherever possible?
- Do showers have flow reducers?
- Are there leaky faucets? They should be repaired.
- Are doors to cooler areas kept closed?
- Are attic vents *above* ceiling insulation open? They should be. The air currents carry away moisture that diffuses into the attic.
- Are exhaust fans used only when necessary?
- Are windows kept closed when heating or air conditioning systems are on?

A heating and cooling checklist

- Are thermostats turned back at night and when there is no one at home? Are they turned to 78°F or above in the summer if there is central air conditioning?
- If there is a fireplace, is the damper closed when the fireplace is not in operation?

- Is the fireplace used on cool and *not* on very cold days?
- Is the heating system equipped with an automatic damper to prevent hot air from escaping up the chimney when the burner is off?
- Is the heating system checked and adjusted at the beginning of every heating season?
- Are heating pipes and ducts that pass through unheated spaces insulated?
- Are the air filters on hot-air furnaces changed or cleaned during the heating season?
- Are radiators or baseboard heaters clean? Are they free of obstructions so that warm air can circulate, thus creating convection currents?
- Is water drained from a hot-water furnace periodically to remove rust and particles that might interfere with circulation?
- If hot-water radiators are present, is air "bled" from them periodically?
- Are air conditioned or unheated rooms closed off from the others?

An insulation checklist

- Is the ceiling well insulated? Is the attic above it well ventilated?
- Are the outside walls insulated? (To find out, if uncertain, turn off the main electric switch, remove the cover plate from an electric outlet on an exterior wall, and look to see if there is insulation in the wall.)
- Are floors over cold areas insulated and carpeted?
- If there is a door to the attic, is it covered with insulation?

INSULATION CAN KEEP A HOUSE OR OTHER BUILDING COOLER IN SUMMER AND WARMER IN WINTER.

An infiltration checklist

- Are there storm doors and windows?
- Are shades and draperies, preferably insulated ones, drawn at night and on cold, dark days. Do they fit tightly?
- Are shades and draperies drawn in summer to reduce solar heating?
- Are doors and windows caulked and weather-stripped? Do they fit tightly?

- Does your draftometer indicate infiltration around doors and windows or wall cracks?
- Are there entrance vestibules to reduce infiltration during entrance and exit?
- Are there windbreaks on the north and northwest sides of the house?

AN ENERGY AUDIT

In Chapter 3 you learned how to determine heat losses due to infiltration and conduction. You can use that knowledge to do an energy audit of the building you are examining.

From the volume of the building and the number of air turnovers per hour (N), which you can obtain by using Table 2 in Chapter 3, the heat required to change a cubic foot of air by 1°F (0.018 Btu/ft^3/°F), and the number of degree-days (DD) in a heating season, you can determine the annual heat losses due to infiltration. You may remember that it is given by:

$$\text{heat losses (Btu)} = \text{volume} \times 0.018 \times N \times 24 \times DD$$

To find the annual heat losses from a building due to conduction, you will need to find the surface areas of ceilings, floors, and walls and the R values of the materials that cover and lie within these surfaces. The R values of a variety of materials can be found in Appendix 1.

The air film on the external surface of a building has an R value of 0.17; the film on the interior surface has an R value of 0.68. Any enclosed air space surrounded by building materials has an R value of 0.9. If the space is bounded by aluminum foil facing inward, the R value becomes 2.17.

The R value for a wall with an internal cover of $\frac{3}{8}$-in gypsum board, filled with $3\frac{1}{2}$ in of mineral wool insulation with aluminum foil facing, and covered externally by $\frac{3}{4}$-in wood sheathing, building paper, and $\frac{1}{2}$-in clapboards can be calculated as follows:

(air film) 0.68 + (gypsum board) 0.32 + (air space bounded by aluminum foil) 2.17 + (insulation) 11 + (sheathing) 1.0 + (building paper) 0.06 + (clapboards) 0.81 + (air film) 0.17 = total R value = 16.21 $ft^2 - h - °F/Btu$.

Before calculating heat losses through the wall area, you will have to subtract the total area of the windows and doors set in the walls.

The heat losses through the surfaces of doors and windows will have to be determined separately after you have established their R values.

A chart that you can design will help you organize your data and calculations.

POTENTIAL SAVINGS

Once you have determined the annual heat losses from the building, you can prescribe changes that will reduce heat losses from the building and hence provide significant savings for the owner.

For example, if there is considerable infiltration due to poor caulking and weather stripping, the cost of materials to repair such problems are so insignificant that it is almost always worth the cost. Adding 7 in of mineral wool insulation to an uninsulated ceiling might cost $300. If such a procedure reduces heat losses by 90 million Btu per heating season, then about 900 fewer gallons of fuel oil would be used. If the oil sells for a dollar a gallon, the owner would get his or her money back in one-third of a heating season—a deal that's hard to beat!

On the other hand, if the ceiling already has 7 in of insulation, another 7 in might save only $50 per year. Would the owner be interested in doing this if the payback period is six years? Maybe, if he or she plans to stay in the house for many years. Maybe not, if the owner might move in a year or two. But only after an energy audit can a homeowner make rational decisions about spending money to reduce energy costs.

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APPENDIX 1

R VALUES OF VARIOUS MATERIALS

Material	*Thickness (inches)*	*R value (sq ft-h-°F/Btu)*
Insulation		
mineral wool batts	1	3.1
mineral wool batts	3.5	11
mineral wool batts	6	19
mineral wool batts	12	38
glass fiber	1	2.2
rock wool	1	2.7
cellulose (paper)	1	3.7
vermiculite	1	2.2
perlite	1	2.7
expanded polyurethane	1	5.9
expanded polystyrene	1	4.7
polyisocyanurate sheathing	1	8.0
Building materials		
wood sheathing	0.75	1.0
plywood	0.50	0.63

bevel-lapped siding	0.50	0.81
gypsum board	0.375	0.32
building paper	—	0.06
vapor barrier (plastic)	—	0
wood shingles	—	0.87
asphalt shingles	—	0.44
linoleum	—	0.08
carpet with fiber pad	—	2.1
hardwood floor	—	0.71
Windows and doors		
single-glazed window	—	1.0
double-glazed window	—	2.0
exterior door (wood)	—	2.0
Masonry		
concrete block	8.0	1.1
brick (common)	4.0	2.0
concrete (poured)	8.0	0.64
Air films and spaces		
air space, between building materials	0.75 or more	0.90
air space, between aluminum foils	0.75 or more	2.17
air film, on exterior surface	—	0.17
air film, on interior surface	—	0.68

APPENDIX 2

SPECIFIC HEATS OF SOME COMMON SUBSTANCES

Material	*Specific Heat (cal/g/°C or Btu/1b/°F)*
Air	0.24
Aluminum	0.214
Asbestos wool	0.20
Asphalt	0.22
Brick	0.20
Cast iron	0.12
Clay	0.22
Concrete	0.22
Copper	0.092
Glass	0.18
Glass wool	0.157
Gypsum	0.26
Ice (0°C)	0.487
Limestone	0.217
Marble	0.21
Sand	0.191
Steel	0.12
Stones	0.21
Water	1.00
White fir	0.65
White oak	0.57
White pine	0.67

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